Industrial Water Treatment

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FOREWORD

This publication provides information about boiler and cooling water treatment that can be used to develop and implement industrial water treatment programs. The purpose of an industrial water treatment program is to allow the equipment to operate as designed. Industrial water treatment achieves this goal by controlling corrosion and the formation of deposits on heat transfer surfaces.

For maximum benefit this manual should be used in conjunction with equipment manufacturers' manuals, parts lists and drawings. In case of conflict, manufacturers' recommendations on use, care, operations, adjustment and repair of specific equipment should be followed. The manual is intended for use by public works officers, supervisors, and operations personnel.

Additional information concerning procedures, suggestions, recommendations or modifications that will improve this manual are invited and should be submitted through appropriate channels to the Commander, Naval Facilities Engineering Command, (Attention: Code 165), 200 Stovall Street, Alexandria, VA 22332-2300.

This publication has been reviewed and approved in accordance with the Secretary of the Navy Instruction 5600.16 and is certified as an official publication of the Naval Facilities Engineering Command

D. B. CAMPBELL
Deputy Commander for
Public Works

ABSTRACT

This publication provides operating and maintenance procedures for industrial water treatment to operate a safe and economical industrial water treatment facility. For maximum benefit, this manual is to be used in conjunction with specific equipment manufacturers' manuals, parts lists, and drawings.

CHANGE CONTROL SHEET

Document all changes, page replacements, and pen and ink alterations posted in this manual.

AMENDMENT NUMBER	AMENDMENT DATE	POST DATE	POSTED BY (LAST NAME)

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SAFETY SUMMARY

Performance without injury is a sign of conscientious workmanship and planned supervision. Therefore, safety is a primary consideration when operating, inspecting, or maintaining any of the systems addressed in this publication.

The first essential action is to read and understand publications associated with systems and equipment king used.. These manuals explain safe and accepted ways of installation, startup, operation, inspection, maintenance, removal, and shutdown. If you do not understand what you have read, **DO NOT** attempt to perform the intended task, get guidance from your supervisor.

All military agencies are subject to the Occupational Safety and Health Standards (OSHA). Portions of the act that apply to operation and maintenance of water plants fall under Part 1910, Occupational Safety and Health Standards, and its subparts. These OSHA standards are implemented at military installations via specific service regulations which are available through the installation's safety, occupational health, and fire department officers. Only general information on health and safety is provided in this manual. Specific instruction and guidelines are in the appropriate service regulations. These should be available in the workplace.

The following general safety notices supplement the safety procedures appearing elsewhere in this manual. They are recommended precautions that should be understood and applied during operation and maintenance of equipment. In addition, equipment operators are reminded that safety instructions, notices, and special orders should be read, understood, and implemented.

The following general rules are emphasized:

- An injury, no matter how slight, shall be reported. Always get first aid or medical attention immediately. Should an individual stop breathing, initiate rescue breathing immediately. A delay could result in loss of life.

- All signs, markings, and tags that pertain to safety measures shall be displayed prominently.

- Follow lockout and tagout procedures in accordance with OSHA standards.

- All personnel should be trained and qualified in cardiopulmonary resuscitation (CPR).

- All personnel should wear safety shoes. Rough-soled safety shoes are preferable for slippery surfaces, as are rubber boots for work in wet areas. Safety-toe workshoes may be worn in all cases, but must be provided where tools or materials may fall. Heavy metal foot guards may be required in some cases, such as when hot, molten lead is being poured, or for jackhammer operators.

- All personnel should wear clothing appropriate to the job being performed. Eliminate loose clothing, which can get caught in machinery.

- Wear work coveralls with long-sleeved shirts and long pants and use gloves impervious to the chemicals (for example, gloves that are vinyl-coated). Rubber aprons or laboratory coats may be needed.

- Wear head protection hats of metal, plastic, or fiberglass crowns suspended on an adjustable headband, when operations are in an area in which tools or materials may fall on the worker. Metal hats will not be used where electrical hazards are likely to exist

- All personnel should wear eye and ear protection prescribed for the task being performed. Personnel should be provided with suitable safety glasses, goggles, cap goggles, or face shields to be worn during any operation in which fragments of materials, chemicals, or fluids containing disease-causing biological organisms, are likely to strike the operator's eyes or face.

- Always use the correct tool or equipment for the job. Safety devices such as handguards, seatbelts, alarms, sequenced manual controls, etc., which are included on equipment should be maintained in working order and used at all times. Minor inconveniences resulting from their use are more preferable than the potential of serious injury that could result from not using them.

- **DO NOT WORK ALONE.** At least one other person should be on hand.

- Always insure that a confined space has been Gas-free Engineered prior to entering the area to ensure that no flammable gases and/or vapors are present. Wear a respirator. Personnel experiencing any difficulties in breathing while working in manholes, deep pits, and empty tanks should immediately get out until the atmosphere can be checked for adequate oxygen content.

CHEMICAL HANDLING

Chemicals used for water treatment and related equipment maintenance will effect people handling them. These chemicals range from highly toxic to mildly irritating. Handle chemicals with extreme care and explicitly follow special instructions and safety data sheets, which are issued by manufacturers. To reduce potential for accidents, practice good housekeeping in all areas where chemicals are handled. With all chemicals, even those you use frequently, observe the following to ensure safety:

- Read label for specific chemical name, kinds of hazards, seriousness of hazard, emergency procedures.
- Store chemicals in closed containers, tanks or cylinders. Follow the advice of the manufacturer.
- Dispose of chemicals by following rules and regulations.

ACIDS -- Avoid splashing acids. If acid comes in contact with eyes, skin, or even clothing, immediate and prolonged flushing with water is necessary. All cases of acid burn must be reported immediately to a doctor. When handling acid, goggles, a face shield, rubber gloves, and an apron must be worn.

When any acid requires diluting, ALWAYS ADD ACID to the water. If water is added to acid, a violent reaction or splattering will occur.

ALKALIES -- Caustic soda (sodium hydroxide) is a strong alkali in both liquid and solid form. If caustic soda comes in contact with eyes, skin, or even clothing, immediate and prolonged flushing with water is necessary. When handling caustic soda, the following precautions should be observed: wear close fitting industrial goggles, rubber apron, rubber gloves, and coveralls that fit snugly around the neck and wrists.

The dust or mist from caustic soda may cause injury to the upper respiratory tract if inhaled. Use extreme caution when adding water to caustic soda; a great deal of heat is generated which can cause splattering or boiling of the solution.

CHROMATES -- Dust from solid chromates can be very irritating. In addition to rubber gloves and goggles, a respirator should be worn when handling them. After working with chromates for any length of time, a shower and change of clothing is recommended.

Liquid chromate solutions are acidic and should be handled with the same precautions that apply to acids. When diluting a chromate solution, **ALWAYS ADD CHROMATE** solution to the water.

Some frequently used water treatment chemicals require awareness of their potential danger; these are hydrazine, morpholine, diethylaminoethanol, cyclohexylamine, and chlorine.

HYDRAZINE -- a colorless liquid with a weak, ammonia-like odor, direct skin contact will cause irritation; continued, or excessive, contact causes systemic injury by being absorbed through the skin. Laboratory studies show that hydrazine is carcinogenic. Do not utilize hydrazine as a chemical oxygen scavenger except when required for certain high purity makeup water boilers. The advantage of its gaseous state is offset by the risks to human health from exposure to either the steam through humidification systems, live steam sterilization units or live steam kitchen operations. **SHALL NOT BE USED** for steam boilers that supply steam for food preparation, e.g., shore-to-ship steam.

MORPHOLINE -- a colorless liquid with a weak, ammonia-like odor; highly irritating to eyes, skin, and respiratory system; direct contact may cause bums; when heated, emits highly toxic nitrous oxide fumes. Do not purchase this chemical in concentrations

in excess of 40 percent solution by weight. Few plants have the necessary equipment to properly and safely dilute this chemical. Therefore, it should be purchased in a concentration of approximately 35 to 40 percent. More dilute solutions are not cost-effective. This neutralizing amine is typically purchased with an approximately equal amount of cyclohexylamine. The total neutralizing amine concentration should never be purchased in concentrations exceeding 40 percent.

DIETHYLAMINOETHANOL -- liquid contact with the skin will cause irritation; liquid contact with the eyes will cause irritation and severe burns; vapors, which have weak ammonia odor, may cause nausea, vomiting, coughing or shortness of breath.

CYCLOHEXYLAMINE -- caustic to mucous membranes; systemic effects include: nausea, vomiting, anxiety, restlessness, and drowsiness; may also be a skin sensitizer. Do not purchase this chemical in concentrations in excess of 40 percent solution by weight. Few plants have the necessary equipment to properly and safely dilute this chemical. Therefore, it should be purchased in a concentration of approximately 35 to 40 percent. More dilute solutions are not cost-effective. This neutralizing amine is typically purchased with an approximately equal amount of cyclohexylamine. The total neutralizing amine concentration should never be purchased in concentrations exceeding 40 percent.

CHLORINE -- highly toxic if ingested, whether as solid, liquid, or gas; externally irritating and injurious to the skin and eyes.

ELECTRICAL WORK

To prevent electrical shock or injury, the following precautions should be observed.

- Do not wear jewelry, including rings, bracelets, necklaces, or wrist watches.
- Do not wear jackets with metal zippers.
- Do not use metal ladders.
- Do not take short cuts. Steps recommended by a manufacturer usually have a margin of safety built into them.
- Be sure that rubber gloves are inspected and air tested on a regular basis.
- Always use insulated tools and grounded equipment. **NEVER USE** screwdrivers or other tools with metal shanks extending through their handle.
- Always use and observe tags and lockouts on circuits.

CHAPTER 1. BACKGROUND, USES, PROBLEMS, AND BENEFITS

1.1 INTRODUCTION. Many industrial processes at naval activities require water. The quality of water required depends upon the process it is to be used for. Steam generating systems require high-quality water; however, open, recirculating cooling systems can tolerate impurities. Impurities in water can result in serious operating problems and wasted energy caused by deposit formation, corrosion of metals, biological fouling, and deterioration of the wood in cooling towers.

1.2 BACKGROUND. Water treatment methods require attention and adherence for the following reasons:

- Energy conservation benefits can result from appropriate treatment.
- Since September 1981, the Naval Sea Systems Command has implemented standards for shore-to-ship steam purity.
- The frequency of boiler operational problems and the need for repairs caused by poor quality water can be reduced, particularly aboard ships that use shore produced steam while in port.
- Concern exists over environmental pollution that can result from water treatment system discharges.
- To reduce maintenance and increase life expectancy on equipment such as air compressors, condensers, cooling tower systems, and refrigeration systems, all of which too often lack clearly defined water treatment requirements.

The user of this manual is advised to refer to Appendices B and C for complementary and supplemental information on industrial water treatment. These documents have been included to avoid loss of available information.

1.3 USES. Water is used at naval facilities in a variety of heating and cooling applications, including the following:

- Heating and power plants, including steam and feedwater supplied to ships.
- Cooling towers for refrigeration systems.
- Cooling for air compressor systems.
- Fire protection and diesel engine cooling systems.

All naval installations use water in at least two of these applications. Some facilities, such as shipyards and fleet operating bases, provide utilities water for

all the applications cited. The water which is treated for industrial use is called makeup water. The most prevalent source of makeup water is potable water, usually pretreated and supplied by a municipal district.

13.1 Heating and Cooling. In general, processes that subject water to the greatest temperatures and pressures require the highest quality water. Specific uses at naval facilities, in decreasing order of required purity, are as follows:

- Shore-to-ship steam and feedwater.
- High-pressure steam heating for power plants.
- Small, low-pressure boilers, including Mobile Utilities Support Equipment (MUSE) boilers.
- High-temperature water systems.
- Low-to-medium pressure heating systems.
- Condenser and cooling tower systems for central plants and refrigeration systems.
- Other cooling water applications, including air compressor plants.

A more detailed discussion of water problems and water treatment for heating and cooling systems appears later in this chapter and in Chapter 4.

1.3.2 Shore-to-Ship Steam. If impure steam is supplied to ships from shore installations, high annual expenditures to repair shipboard systems will result. This occurs because steam is condensed aboard ship and returned to the ship system, and poor quality water causes corrosion and scaling on waterside surfaces. The **NAVSEASYSCOM** shore- to-ship steam purity standards are as follows:

Steam supplied directly to ships or condensed for use as feedwater shall be generated from feedwater which is either treated with a chemical oxygen scavenger or mechanically deaerated to a maximum dissolved oxygen content of 15 parts per billion. Shore steam and condensed shore steam used as feedwater shall meet the following requirements:

Characteristic	Requirements
PH	8.0 to 9.5
Conductivity	25 micromho/cm max
Dissolved silica	0.2 ppm max
Hardness	0.10 epm max
Dissolved Oxygen	15 ppb max

These requirements are specified in NAVSEA S9086-GX-STM-020, Chapter 220, Volume 2, **Boiler Water/Feedwater Test and Treatment** and PACDIV P-200. Copies of the results of testing are to be forwarded to the appropriate **NAV-FACENGCOM** Engineering Field Division every month. Also contained in the **NAVSEASYSCOM** and **NAVFACENGCOM** documents are requirements for purity of shore-processed feedwater.

      1.3.3 Fire Protection and Other Uses. Salt water or brackish water is often used in firemain systems at waterfronts. These distribution systems provide water at pressures of 100 to 150 psi. This lower quality water is sometimes used for condenser cooling. Fresh water is normally used away from waterfront areas.

1.4 PROBLEMS. The direct results of poor quality water are corrosion and scale deposits. All water-related problems stem from these factors.

      1.4.1 Corrosion. Corrosion is an electrochemical process involving the oxidation of a metal. Deterioration can cause the failure of essential components such as boiler tubes, steam lines, air compressor coolers, and firemains. Corrosion problems cost millions of dollars each year in avoidable repair work and equipment downtime. A detailed discussion of the mechanisms of corrosion control is beyond the scope of this document. However, a variety of texts are available on the subject which can be of assistance to anyone interested in more detail. The following books are available in major bookstores[1]:

CORROSION AND CORROSION CONTROL - An Introduction to Corrosion Science and Engineering, Edited by Herbert H. Uhlig, John Wiley & Sons, 1985.

CORROSION BASICS - An Introduction, Edited by L.S. Van Delinder, NACE, 1984.

CORROSION AND ITS CONTROL - An Introduction to the Subject, Edited by J. T. N. Atkinson and H. Van Droffelaar, NACE, 1982.

INTRODUCTION TO CORROSION PREVENTION AND CONTROL - P. J. Gellings, Delft University Press, 1985.

CORROSION ENGINEERING - Mars G. Fontana, NACE, 1986.

THE CORROSION HANDBOOK - Edited by Herbert H. Uhlig, John Wiley & Sons, 1948.

CORROSION ENGINEERING - Mars G. Fontana & Norbert D. Greene, Mc-Graw- Hill Book Company, 1967.

[1]Note: The National Association of Corrosion Engineers (NACE) also provides a book service which includes all of these texts. NACE Publications Office, P.O. Box 218340, Houston, Texas 77218.

1.4.2 Scale. Scale deposits result from solids and organic growths adhering to surfaces, such as pipe walls. In a heat transfer application, such as a boiler tube, scale acts as an insulator and reduces the rate of heat transfer. Inhibiting heat transfer causes loss of efficiency, increased fuel consumption, and elevation of tube temperatures to the point that metal weakens and tubes rupture. Scale buildup also increases pressure drop and decreases water flow in pipes. This clogging effect results in both an increase in pumping power required to circulate water and a loss of efficiency. Table 1-1 lists problems caused by impurities in water as they relate to various water applications. Figure 1-1 illustrates corrosion and scale problems in boiler plant and cooling tower components. Figure 1-2 illustrates how heat transfer is affected, even by thin layers of scale. Table 1-2 displays problems caused by specific impurities and suggested treatment methods where water is to be used in boilers.

1.5 BENEFITS. A well-managed water treatment program will minimize scale buildup from. organic and inorganic sources and significantly reduce corrosion potential. Maintenance of good quality water will result in reduction of the following:

- Equipment downtime.

- Operating and repair costs.

- Energy consumption by increasing heat transfer efficiency.

- Energy loss in boiler blowdown,

- Environmental pollution by decreasing harmful effluent discharges.

1.6 SUMMARY. In this chapter, uses of water, problems of poor quality water, and benefits of a good water treatment program have been presented. Chapter 2 presents information on managing a water treatment program, including how to identify problems, how to set up and maintain an effective program, and where' to obtain assistance. Chapters 3 through 7 provide technical background information.

TABLE 1-1

General Problems Caused by Impurities in Water
(Courtesy Drew Chemical Company)

Problem	Application (See Key)						
	A	B	C	D	E	F	G
Uniform corrosion	X	X	X	X	X	X	X
Localized corrosion	X	X	X	X	X	X	X
Stress corrosion					X	X	
Dezincification of brass	X		X	X			X
Ammonia attack of brass			X	X			
Dissimilar metal corrosion	X	X	X	X			X
Chloride attack of stainless steel	X		X				X
Acid Attack			X				X
Caustic attack						X	
Hydrogen damage						X	
Formation of inorganic deposits	X	X	X	X	X	X	X
Microbiological fouling	X		X	X			X
Deterioration of cooling tower lumber			X				
Carryover					X	X	

Key:
A. Once-through cooling water systems
B. Closed, recirculating coolingwater systems
C. Open, recirculating cooling water systems
D. Air-conditioning systems
E. Low-pressure steam generating systems
F. High-pressure steam generating systems
G. Process water
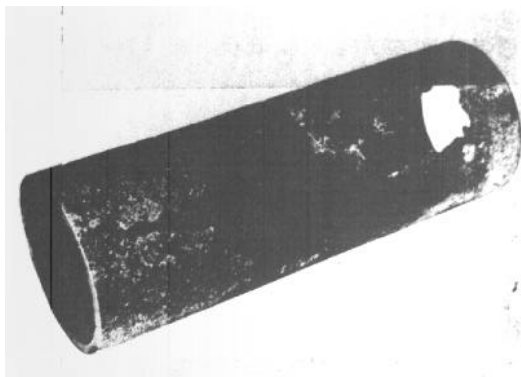
SECTION OF CONDENSATE LINE DESTROYED BY CARBON DIOXIDE (LOW pH) CORROSION. METAL DESTRUCTION IS SPREAD OVER A RELATIVELY WIDE AREA, RESULTING IN THINNING.
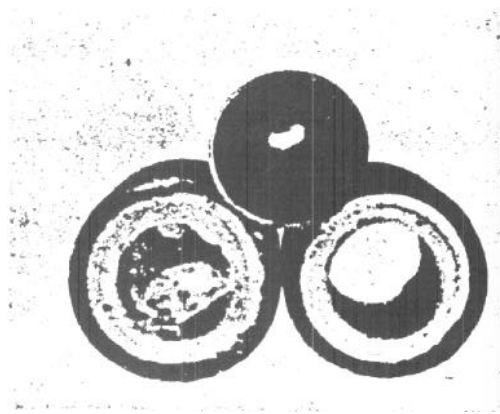
SCALE BUILDUP IN COOLING WATER LINES (HIGH pH).
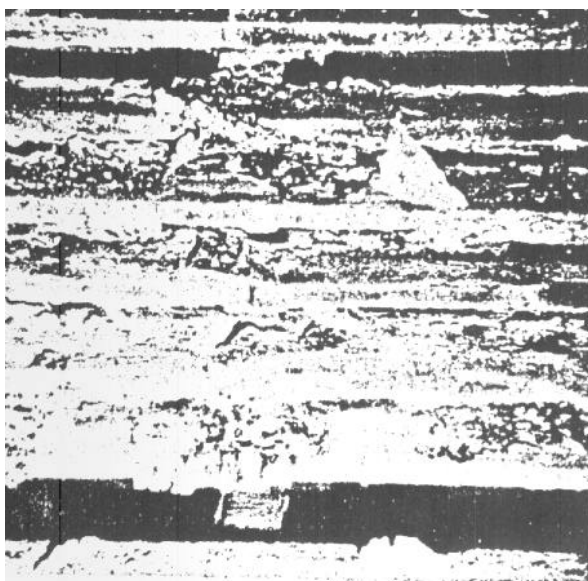
CALCIUM PHOSPHATE SCALE ON COOLING SLATS.
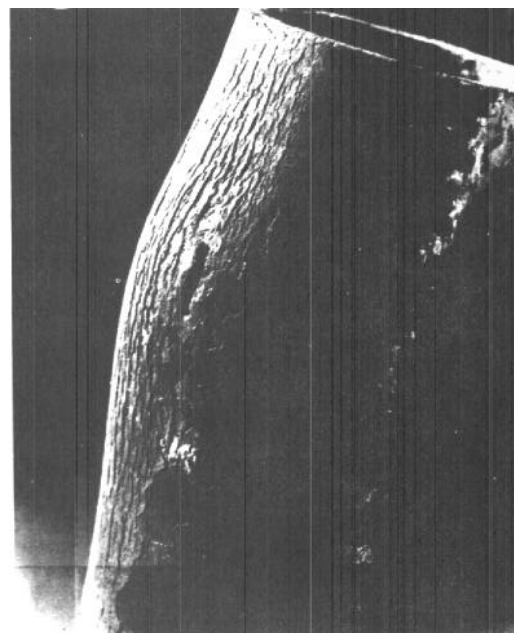
TUBE BLISTER DUE TO PERIODIC OVERHEATING. NOTE FISSURE AND CREEP CRACKS, TYPICAL OF ALTERNATE OVERHEATING AND COOLING.

FIGURE 1-1
Corrosion and Scale in Boiler and Cooling Tower Components
(Courtesy Betz)
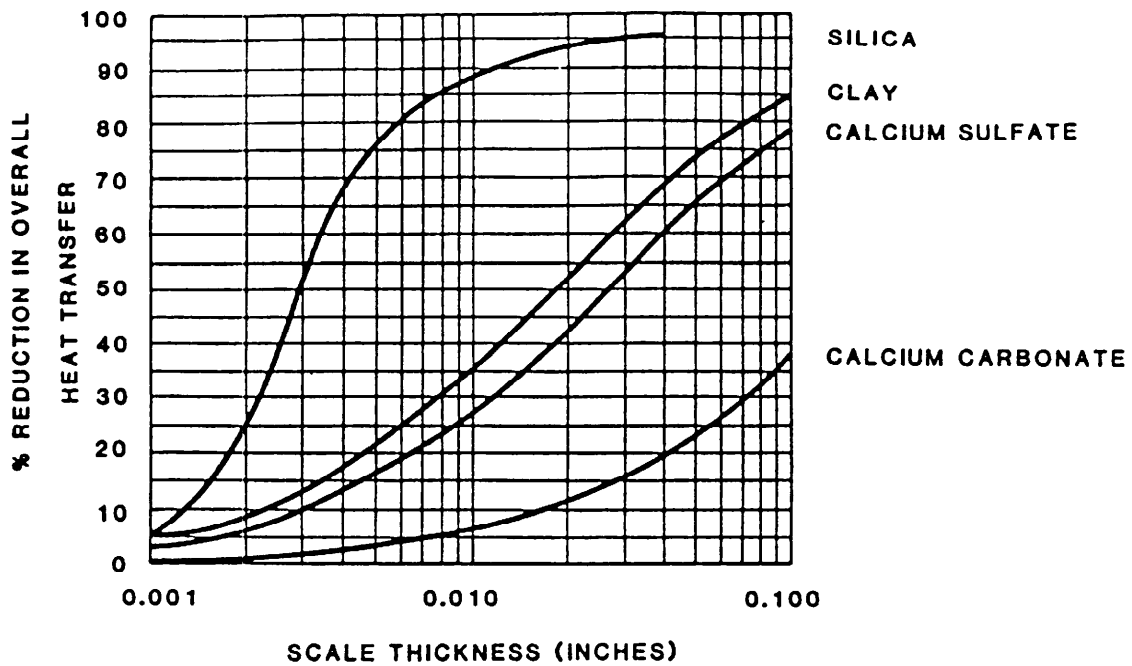
FIGURE 1-2
Influence of Scale on Heat Transfer

TABLE 1-2

Common Impurities in Water and Possible Effects
When Used for Boiler Feed Purposes

Treatment for Removal From Water	Constituent	Chemical Formula	Principal Source of Contaminating Substance	Possible Effect When Present in Boiler Water
Evaporation and demineralization by ion exchange materials	Sodium carbonate	Na_2CO_3	Mineral deposits	Priming, foaming, embrittlement
Evaporation and demineralization by ion exchange materials	Sodium bicarbonate	$NaHCO_3$	Mineral deposits	Priming, foaming, embrittlement
Deaeration	Carbonic acid	H_2CO_3	Absorption from the atmosphere, mineral deposits, decomposition of organic matter	Corrosion
Deaeration	Oxygen	O_2	Absorption from the atmosphere	Corrosion
Coagulation, filtration, evaporation	Grease and oil		Industrial wastes	Corrosion, deposits, priming, foaming
Coagulation, filtration, evaporation	Organic matter and sewage		Domestic and industrial wastes	Corrosion, deposits, priming, foaming
Scavenging oxygen and raising condensate pH using catalyzed hydrazine	Carbon dioxide	CO_2	Decomposition of bicarbonate and carbonate alkalinity. Free carbon dioxide in raw water. Use of soda ash for internal treatment, and decomposition of some organic compounds	Corrosion, deposits

CHAPTER 2. MANAGING A TREATMENT PROGRAM

2.1 INTRODUCTION. This chapter begins with a brief presentation of background information on the importance of water treatment in boiler and cooling water systems. The balance of the chapter deals with how to manage (plan, organize, execute, and control) a high-quality water treatment program. Guidelines are presented for managing a water treatment program applicable to most situations. Modifications may be necessary to adapt the program to particular needs.

2.2 BACKGROUND. Water is often called the universal solvent because of its ability to dissolve, to some extent, practically everything. This characteristic is especially important to process water users and plant operators. While additives, either dissolved or suspended, can improve water quality for some uses, in most instances impurities cause corrosion, scale, deposits, carry over and fouling, which lead to inefficient operation, and eventual failure of plant equipment. Fast detection and correction of parameter abnormalities or treatment deficiencies are essential to managing and maintaining an effective treatment program.

      2.2.1 Boiler Systems. The objective of feedwater treatment is control of boiler water chemistry. By doing this, scaling, corrosion, carryover, and embrittlement can be either reduced or eliminated. Feedwater treatment consists of both limiting introduction of contaminants into the boiler and introducing internal treatment chemicals to maintain water chemistry at desired levels. As boiler pressure increases, higher quality water is required. Boiler feedwater is usually a combination of makeup and returned condensate, with treatment requirements varying with proportions of makeup to condensate (condensed steam). Regardless of the source or quality of the feedwater, some solids will pass into the boiler. Therefore, levels of treatment chemical residuals are important control parameters that must be monitored.

Controlling Solids. The accumulation of solids in a steam boiler is controlled by blowdown. Blowdown consists of draining some of the boiler water with its accumulated solids, and replacing it with treated feedwater before harmful levels of solids are reached. Dissolved solids tend to concentrate near the water surface in the steam drum. Therefore, surface blowdown is most effective in reducing the concentration of dissolved solids. Bottom blowdown is employed to remove precipitated sludge from the boiler mud drum. However, blowdown results in the: loss of heated water and treatment chemicals. Economical operation requires careful control of blowdown to maintain safe solids levels, while minimizing both heat and chemical additive losses.

Condensate Monitoring. The condensate return system is a revealing point for monitoring total system performance. The amount and nature of condensate contaminants will often help identify both carryover and corrosion problems

and help determine corrective action. Identification of contaminant sources and control of treatment systems depend on careful monitoring of key parameters. For example, excessive hardness, conductivity, and turbidity can indicate in-leakage through heat exchangers and condensers; iron, copper, and dissolved oxygen can indicate corrosion; and sodium or silica in condensate can indicate carryover.

      2.2.2 <u>Cooling Water Systems.</u> Cooling water systems are used to remove heat from engines, air compressors, refrigeration condensers, and steam power systems. These cooling systems are classified as either once-through or recirculating. Once-through systems often require nothing more than chlorination to prevent biological fouling of heat exchangers. Treatment is more critical in open, recirculating systems because of solids buildup due to evaporation. As hardness and other solids increase, probability of mineral scale formation in heat exchangers increases. To combat scale damage, chemical additives are used to keep scale-forming salts in solution.

Cooling Towers. Corrosion in cooling tower systems can be general or localized. Dissolved oxygen and carbon dioxide enhance corrosive attack. Corrosion control is provided by addition of inhibitors. In general, chemical attack can be controlled by maintaining constant pH and appropriate levels of alkalinity and inhibitor residual. Slime accumulation and fouling may be prevented by addition of chlorine or other biocides. However, excess chlorine concentration in conjunction with alkalinity in water can be destructive to wood lignin. Solids concentration is controlled by blowdown. In all instances, monitoring for hardness, pH, inhibitors, chlorine, other chemical additives, and solids is essential for cost-effective treatment.

2.3 PLANNING. In planning a water treatment program, one should first determine water quantity and quality requirements. This assessment should include an inventory of the number and types of systems that require high quality water. Also required is a determination of purity specifications, existing water quality, and equipment condition for each application. Applicable standards should be reviewed. Standards are included in the following documents:

- NAVSEA S9086-GX-STM-020, Chapter 220, Volume 2, **Boiler Water/Feedwater Test and Treatment.**
- NAVFAC DM-25.02, **Dockside Utilities For Ship Service.**
- American Society of Mechanical Engineers (ASME).
- Manufacturers of specific equipment.

2.3.1 <u>System Surveys.</u> Systems to be surveyed include large central steam and power plants, smaller heating boilers, cooling towers, engines, high temperature hot water systems, and air compressors. For each system or independent portion thereof, the following information should be gathered and evaluated in the planning phase:

- Quantity of water required: Volume and rate.
- Quality of water required: pH, conductivity (TDS), hardness, silica, dissolved oxygen, and other factors.
- Quality of the existing water supply.
- Instrumentation required
- Type and condition of existing instrumentation.
- Evidence of scale, corrosion, and &posits in system components.

Water quality requirements for specific applications are discussed in Chapter 6. Based on the information obtained, requirements in terms of staff, equipment, and procedures can be developed

2.4 ORGANIZING A TREATMENT PROGRAM. Once water treatment requirements have been defined, personnel should be organized to implement the program. The organization process consists of identifying a staff, training them to execute the program, and integrating the program into overall installation management.

2.4.1 <u>Operator Training.</u> Operator training is essential to a water treatment program. Operators should understand the operation of their specific plant, and reasons for specified procedures, including requirements of 1910.1200. An understanding of reasons for, and results of, chemical treatment is essential. Knowledge of thermodynamic and mechanical interactions of plant equipment is important. The operator should be particularly aware of safe operating procedures. Since internal chemical treatment of boiler water is a significant factor in achieving reliable and efficient plant operation, operators should have an understanding of the subject. Training should be provided in the specifics of water treatment and related costs.

Pretreatment Training. Pretreatment is necessary to ensure the quality of the water to be treated for industrial use and to prevent/reduce associated problems, such as deposits and corrosion. Methods of pretreatment that training might address (depending upon the type of plant) are:

- Chemical addition.
- Ion exchange.
- Reverse. osmosis.
- Distillation

Treatment Training. Steam boilers, high temperature water systems, and cooling water systems all require treatment of feedwater to prevent/reduce deposits, scale, corrosion, and microorganisms.

  Boiler Water Treatment. The training related to boiler water treatment should address the following areas:

- Necessity for internal boiler water treatment.
- Deaeration and oxygen scavenging.
- Maintenance of concentration levels.
- Causes/effects of deposits, scale, and corrosion.
- Chemical treatment programs: Phosphate, polymers, sulfite, hydrazine, and others.
- Where to feed chemicals.
- Effects of carryover and silica on steam purity.
- Prevailing ASME and internal standards.
- Corrosion in condensate returns from oxides of iron and copper.
- Effects of filming and neutralizing amines and hydrazine.
- Boiler layup procedures.

  Cooling Systems Treatment. Training for treatment of cooling systems feedwater
should address:

- Once-through cooling water systems.
- Recirculating cooling water systems.
- Need for and means of maintaining clean condensers.
- Chemicals and methods of treatment.
- Cycles of concentration.

  Blowdown. Blowdown is used in both cooling and steam systems to regulate cycles of concentration of solids through dilution with makeup water. Training associated with blowdown procedures should include:

- Surface versus bottom.
- Internal provisions.
- Estimating blowdown.
- Continuous and intermittent.

- Controllers and cycles of concentration.
- Heat recovery through flash tanks and heat exchangers for boilers

Program Content. Training should be provided in steps that are geared to operators' capabilities. Weekly sessions, with handouts, periodic reviews, and testing should. be planned to assess trainees' retention and understanding of material and effectiveness of teaching methods. Assistance in establishing a training program should be obtained from the regional **Engineering Field Division (EFD)** before going to other sources. In addition, a videotape training course, Power Principles, is available. The course contains 80 tapes on various subjects related to power plant operations, student texts, and instructor guides. Four one-hour videotapes address Basic Water Chemistry and four one-hour tapes address Water Treatment Equipment. Each tape is divided into six ten-minute sections. The tapes cover the following subject areas:

- Basic Water Chemistry.
- Chemistry Concepts.
- Water Chemistry Fundamentals
- Elementary Water Treatment.
- Water Chemistry Applications.
- Water Treatment Equipment.
- Boiler Water Treatment.
- Raw Water Treatment.
- Ion Exchange.
- Cooling Water Treatment.

Additional information about this program can be obtained from your geographical **Engineering Field Division (EFD).**

     2.4.2 <u>Equipment and Procedures.</u>   A description of water quality instrumentation and treatment equipment for various applications is contained in Chapter 7. Procedures are discussed in paragraph 2.5 of this chapter. The subject is also covered in Appendix C.

2.5 EXECUTION. An effective water treatment program includes establishment of an inspection and monitoring program, and development of a reporting system. Reports keep the manager informed on the status of water quality and water treatment programs. Detection and correction of abnormalities or inadequate treatment are essential to managing and maintaining an effective program. This

is accomplished by routine inspection and frequent, consistent monitoring. Instrumentation and laboratory analysis equipment should be checked for specified operation on a regular basis.

2.5.1 Steam Plant Monitoring.   In addition to monitoring manned steam plants, it is also necessary to follow a plan for monitoring unmanned plants. Neglecting them will eventually require expensive repairs instead of minor maintenance. In continuously manned plants, operators and laboratory personnel might monitor and log the systems addressed in the following paragraphs depending upon the size of the plant, the characteristics of the makeup water and the quality required of the output steam.

External Feedwater Treatment System Effluent. Every 4 hours hardness, conductivity, and silica should be monitored to ensure operation within specified limits. Deviation from acceptable limits indicates improper operation, equipment failure, or change in source water.

Deaerator Effluent. Dissolved oxygen and water temperature should be checked daily to ensure that residual oxygen is less than the established limit (usually between 0.04 and 0.05 mg/L) and that water temperature is close to steam temperature in the deaerator. If parameters are not as required, check deaerator venting, steam supply, and internals for either plugged spray nozzles, inverted trays, or corroded trays and baffles.

Boiler Water. Inspect for the following:

Conductivity: Check boiler water every shift to determine if conductivity (and thus total dissolved solids (TDS)) is within specified operating range. Increase or decrease continuous blowdown rate to achieve the specified reading. Boilers with automatic conductivity controlled blowdown valves should be checked for proper calibration. (Special Note: The automatic controller is measuring the conductivity without benefit of neutralization. The correction factor between neutralized and alkaline conductivities must also be regularly checked.)

pH: Check every shift. If not within specified range, adjust chemical feed or other
controlling factors.

Oxygen Scavenger: Check by chemical test once each shift. Adjust the residual, when required, by modifying the stroke or speed of the feeder pump, or the concentration in the feed tank. NEVER MODIFY BOTH AT THE

SAME TIME. (Note: the presence of residual oxygen scavenger is not a means to evaluate the performance of a deaerator.)

Total Alkalinity/Causticity: Check by chemical test once each shift. Caustic feed should be adjusted, as required, to maintain specified level. Excessive alkalinity is controlled by increasing the blowdown rate.

Phosphate or Polymer: Check phosphate levels by chemical test once each shift. Adjust chemical feeders, as required, to maintain recommended residual level. Polymer feed rate may also have to be altered when adjustments are made to phosphate chemical feed rates.

Silica: Check daily for silica level in boiler water only at plants with high silica levels in the makeup water. High silica levels are defined as naturally occurring concentrations of silica that limit the cycles of concentrations in the boiler. For other plants the silica levels should be checked monthly. If levels exceed the specified limit, blowdown should be increased. An investigation should then be initiated for the source of silica intrusion.

Condensate. Returned condensate should be checked at least daily for conductivity and hardness. The pH of condensate should also be checked, because low pH will indicate presence of carbonic acid, a cause of corrosion. If an increase over prescribed limits for conductivity or hardness is observed, a complete laboratory analysis should be performed to determine the source of contamination. Analysis should include iron and copper determinations. When significant impurities are detected, condensate should either be diverted to another use or discarded until the source of contamination has been located and eliminated.

Hot Water Systems. Hot water systems should be sampled for contamination and other abnormalities whenever the system is flushed or modified, and at the following frequencies:

Less than 0.35 MBTU	At Installation
0.35 to 1 MBTU	once/year
1 to 5 MBTU	once/6 months
5 to 20 MBTU	once/3 months
20 MBTU & greater	once/month

2.5.2 Cooling Tower Monitoring. Cooling tower basin water should be controlled to maintain water quality at optimum conditions with minimum fouling, scaling, and deterioration by monitoring the following conditions by

plant operators or roving patrols.

Conductivity (TDS): Depending on makeup supply water and system operating parameters, basin water solids should be controlled to a range of one to seven cycles of concentration. That is, solids concentration in the basin should be about seven times that of the makeup supply water. This parameter varies with makeup water quality. Basin water solids (monitored by checking conductivity) should be checked weekly and continuous blowdown adjusted to maintain a desired level of solids concentration.

pH: Control of basin water pH is essential to minim& deposition of scale and to reduce corrosion. The pH should be checked weekly and the acid/chemical feed adjusted accordingly to maintain pH and alkalinity within acceptable limits. Towers using concentrated sulfuric acid should be equipped with pH alarms to detect very low excursions in pH. Condenser water at a pH below 2 units can perforate the wall of a 10" diameter steel pipe within only a few days after the pH excursion.

Corrosion Inhibitor: Since corrosion inhibitor is lost in blowdown, the feed rate of inhibitor should be checked and adjusted whenever the basin blowdown rate is adjusted. Chemical dispersant should be added with inhibitor to precipitate and fluidize some solid constituents in the basin water.

Biocide: Biological growth occurs in many cooling towers, heat exchangers and basins. Concentration of cooling water biocides that inhibit biological growth, should be checked weekly. Biocide feed rate should be adjusted in relation to the: makeup water supply rate and visual indications of their effectiveness.

Total Hardness: When used in conjunction with cycles of concentrations, provides a comparative value for determining the scaling tendencies of the water. The test is relatively simple and may be performed in the field.

Bacterial Level: Visual means of reporting algae accumulation are subjective and algae is not the primary microorganism responsible for cooling tower equipment failures. Bacteria contribute more to slime fouling and corrosion. Bacterial levels provide a good indication about the effectiveness of biocides before damage to cooling tower equipment is evidenced. An approved "dipstick" field test method may be used to determine bacterial levels.

Maintenance: Inspect daily for operation of automatic chemical feed equipment, renew chemicals, and send weekly water samples to the laboratory for analysis. Make weekly adjustments, based on laboratory analyses. Prompt

repair and maintenance should be provided for automatic feed and control equipment and a complete record should be maintained for each tower.

2.5.3 Inspections.   Routine periodic inspections should be conducted, in addition to daily monitoring. For cooling towers, quarterly inspections should be performed and can be made when the tower is operating. Scale, slime, algae, and wood deterioration are visible problems. Inspection is less frequent for boiler plants, since a boiler must be shut down to perform an inspection. Inspections are normally annual, but every major shutdown should be regarded as an opportunity. Scale samples should be taken from sludge in the boiler drum and scraped from the tubes for analysis. The thickness of scale on, or in, the tubes should be estimated and reported. Water treatment affects corrosion and sealing on the water side of heat exchangers, coolers, and refrigeration condensers. Water treatment equipment should be inspected and evaluated in the same manner as systems using the treated water.

2.5.4 Reports.   Managers should receive a monthly summary of inspection and monitoring program data. A sample monthly report is provided in Appendix B. For a large, continuously manned central boiler plant, the report should contain results of daily tests, in graph form, exhibiting the following data:

- Conductivity (TDS).
- pH.
- Hardness.
- Dissolved oxygen.
- Alkalinity.
- Silica (for boiler plants with restricting levels of silica in the makeup water).
- Chemical residuals.

The report should also include the following:

- Fuel consumed per pound of steam.
- Pounds of steam produced.
- Makeup water used.
- Condensate returned.
- Hours of operation.
- Chemicals consumed.
- Blowdown rate.

The summary report should include, on each graph, allowable limits of the respective parameters, facilitating quick assessment of acceptability and trends of reported results.

For smaller plants and low-pressure boilers, the monthly report should include:

- Conductivity (TDS).
- pH.
- Hardness.
- Dissolved oxygen.
- Chemical residuals.
- Alkalinity.
- Steam produced, makeup water used, and condensate returned.
- Chemicals consumed.

Similarly, quarterly cooling tower reports should provide the following data:

- Conductivity (TDS).
- pH.
- Corrosion inhibitor residual level.
- Biocide residual content.
- Makeup water consumption.
- Blowdown rate.

Managers should receive all routine inspection reports. Equipment condition reports indicate the adequacy of a water treatment program. Inspections should be conducted on the following schedule:

System	Minimum Frequency
Boilers	Annually or on every major shutdown
Cooling Towers	Quarterly
Heat Exchangers	Same as boilers
Condensers	Same as boilers

2.6 CONTROLLING A TREATMENT PROGRAM.

2.6.1 Setting Standards. Both requirements and standards development are discussed in paragraph 2.3, the planning phase. Once a water treatment program has been implemented, it is necessary to continuously review results to determine if requirements are being met. Examples of standards for boiler plants appear in Tables 5-1A through 5-1D. The manager should be sensitive to any change in requirements that necessitate modifications to the program.

2.6.2 Appraising the Program. The manager should periodically check results of a water treatment program. The following lists contain parameters to be checked in evaluating the adequacy of a water treatment program and possible problem sources.

Makeup Water

- Adequacy of supply.

- Analysis of source water--comparison with quality required.

- Seasonal variations in source water quality.

- Adequacy of treatment system capacity.

- Analysis of treatment systems effluent--comparison with process requirements (seasonal variations should be considered).

- Treatment system operation--labor required; adequacy of instrumentation and controls; visible evidence of component corrosion, deterioration, or malfunction.

Boiler Systems

- Evidence of deposits, scaling, or corrosion in the system--analysis of deposits.

- Adequacy of deaerator operation--suitable vent plume (continuous and minimum height of 18 inches), water temperature, and residual oxygen content.

- Total dissolved solids within prescribed limits; too low a reading indicative of excessive blowdown and waste of heat, water, and chemicals (refer to Tables 5-1A through 5-1D for examples of limits).

- Chemical residuals--phosphate, oxygen scavenger, and other chemicals within limits recommended by supplier; too high residual content is indicative of faulty, wasteful feed rate; too low, inadequate protection.

- pH--as per Tables 5-1A through 5-1D

Steam and Condensate System

- Evidence of corrosion, particularly where condensate forms or flows--indicative of carbon dioxide and/or oxygen in system, result of faulty water treatment and/or infiltration into condensate returns.

- Excessive carryover--check for deposits in saturated steam header; check steam quality by calorimeter or ion detector; usually results from excessive alkalinity or solids in boiler water or generally high boiler water levels.

- Iron, copper, or hardness in condensate--indicative of corrosion in system or infiltration from external sources.

Cooling Water Systems

- Visible condition of cooling tower and basin: algae, slime, or mold--indicative of insufficient biocide; metal corrosion--insufficient inhibitor or excessive acid feed; deterioration of wood members--excessive chlorine or alkalinity; deposits or scale--excessive solids (insufficient blowdown), inadequate chemical treatment, or insufficient acid feed.

- Waterside of heat exchangers: scale, deposits, or corrosion--evidence of inadequate chemical treatment; fouling--insufficient biocide.

- Once-through systems--check for visible indications of fouling, plugging, and organisms.

Treatment Costs

- Cost per unit for treated makeup water compared to other similar treatment systems.

- Costs for internal treatment chemicals per unit of production, compared to costs for similar systems.

Operating Records and Reports

- Maintenance of complete and accurate operating logs of water treatment systems.

- Accurate records of chemical consumption, plant loads, chemical costs.

• Reliable recording of maintenance operations and costs.

2.6.3 Corrective Action. The above information allows a manager to assess adequacy of treatment practices, to identify problems, and to develop an action plan Information for solving problems is contained in the balance of this chapter.

Solving Problems In-House

Assuming that the treatment program is followed, and that monitoring and inspection reports indicate that treatment is ineffective, the following steps should be taken,

• Review supply water analyses. Determine if significant changes have occurred since initiation of the treatment program.

• Review the adequacy of performance parameters for the treatment system, such as capacity and quality of source water and of effluent.

• Determine if significant changes have occurred in plant operating conditions.

• Review performance of personnel who make tests and adjustments.

• Consult with the on-site water treatment specialist regarding additions to, or changes in, treatment practices. Discuss with your geographical **Engineering Field Division.**

• Try to determine why treatment is ineffective: competence of personnel, chemicals, dosages, changed conditions.

• Adjust program as necessary. CHANGE ONLY ONE PARAMETER AT A TIME. Results should be monitored closely to determine the changes that have the most beneficial effect.

• In 'case of gross problems, an entire treatment program may need modification. If this is planned, all equipment, boilers, heat exchangers, and cooling towers should be descaled, cleaned, and repaired. This allows evaluation of a modified treatment program.

Solving Problems with Outside Consulting. Several alternatives to problem solving are available: hire a consultant, confer with a chemical supply company specializing in water treatment, or contract for water treatment services. Selection of one or more of these courses of action depends on available financial resources and the magnitude of the problem

Consultant services. One option is to contract for services of a consultant to provide management oversight of a water treatment program. As a minimum, the contract should specify that the engineer in charge of these services shall be accredited as a corrosion specialist by the National Association of Corrosion Engineers (NACE). NACE can be contacted to verify the accreditation of an individual at Box 218340, Houston, Texas 77218 (713) 492-0535. The consulting firm should also not be affiliated in any way with the sale of water treatment chemicals. An example of contract specifications for this type of service is as follows:

A thorough check of plant operating conditions shall be made each month. Tests of untreated supply and cooling tower water shall be made, as required, during regular monthly visits.

During each monthly service visit, the service engineer shall review records of control tests of the steam generating plants, discuss these with plant personnel, and offer comments or constructive criticism. The service engineer shall conduct tests and inspections needed to check accuracy of recorded data. After each service visit, and before the engineer leaves the station, recommendations shall be submitted, in writing, to the Public Works Officer with a copy to the Contracting Officer.

Report forms shall be furnished by the service contractor for recording, in duplicate, results of daily tests performed by plant personnel. Constructive criticism of these reports shah be submitted, in writing, monthly. Daily reports shall be reviewed promptly and, if results indicate need for revisions in control procedures, recommendations and/or instructions shall be issued immediately, in writing, to the Public Works Officer with a copy to the Contracting Officer.

During each monthly service, water samples shall be taken from specified points in the plant systems for analysis by the service contractor. Analysis of samples constitutes an additional check on the accuracy of plant tests. Analyses, together with plant control tests and the reports of the service engineer, serve as a basis for a complete review of plant conditions by the service contractor.

Tests of untreated supply water that constitute makeup for boiler feedwater and control tests on cooling tower water shall be performed as required.

The service engineer shall be responsible for instructing plant operating personnel in test methods. The service engineer shall assist in inspection of internal boiler surfaces and feedwater equipment; such inspections shall normally be conducted once during the contract period, unless an unusual condition should

develop that requires more frequent inspection. Inspection is for the purpose of providing consulting advice regarding conditions found by the service contractor.

Water Treatment Chemical Supply Companies. Water treatment chemical supply companies are found in metropolitan areas of all large cities in the U.S. In addition, nationwide organizations have branch offices and distribution facilities in all major metropolitan areas. These are the companies that have developed the science of internal chemical water treatment. **Federal Supply Schedule** (FSC Group 68, Part 5, Sections B and C, Class 6810 and 6850) provides a list of chemical suppliers and treatment services. Most companies issue bulletins describing water treatment products and services offered. The product listings are especially informative. When dealing with a specialist company, one should be aware that each firm promotes only its own products. One should not hesitate, however, to ask questions regarding competitive products. Some products and formulations are uniquely suited to specific problems. Before buying or contracting for trade name products for water treatment, investigate ingredients thoroughly to ascertain whether or not a generic product is available through the Government supply system at substantially reduced cost. Water treatment services should not be automatically renewed year after year, but should be reviewed with respect to what competing companies offer. Most importantly, services of the company engaged should be judged on the basis of results. Adequacy should be assessed, including the cost of the program.

Contracting for Water Treatment Services. In organizing a water treatment management program, an activity may choose to contract for all, or a portion of, required services. Regional EFD personnel should be included in program formation. The contracting decision will be affected by factors such as size and complexity of the plant or plants to be operated and maintained, available pool of labor, and skills and level of training and education of personnel. At the very least, procurement of internal treatment chemicals should include periodic visits and tests by the supplier's specialists to determine that recommended dosage rates and residual concentrations are maintained.

Full Service Contracts. Another alternative is to contract for a complete treated water supply and water treatment management package. This can include installation and operation of a water treatment facility, either fixed or trailer mounted, or the supply of treated water by tank transport for low volume requirements. In such cases, the contractor can provide all services required for testing and maintaining chemical treatment systems.

2.6.4 Water Treatment Devices. The water treatment market has an abundant supply of devices or gadgets purporting to end all problems, and to

replace all chemical treatments. Devices claim to use magnetics, ultrasonics, or electrostatics to control scale, corrosion, and algae in boiler and cooling tower water systems without use of chemicals and with little or no expenditure of energy. Policy regarding this matter is covered in NAVFACINST 11300.37, "ENERGY AND UTILITIES POLICY". The use of unproven or unapproved devices or methods could result in significant damage to systems and equipment.

CHAPTER 3. CHARACTERISTICS OF WATER

3.1 INTRODUCTION. Few engineering or industrial operations can be performed without a conditioned water supply. Pure water is tasteless, colorless, and odorless. Water molecules are composed of two atoms of hydrogen and one atom of oxygen. Water possesses several unique properties; among these are a tremendous capacity to absorb and store heat and ability to dissolve everything, to some degree. Because of this solvent property, water contains impurities. These impurities are the source of scale that deposit in lines, boiler tubes, and other surfaces that come in contact with water. Dissolved oxygen, one of the principal gases present in water, can be significantly responsible for corrosion of metals. Figure 3-l illustrates effects of oxygen corrosion and scale buildup on water piping.
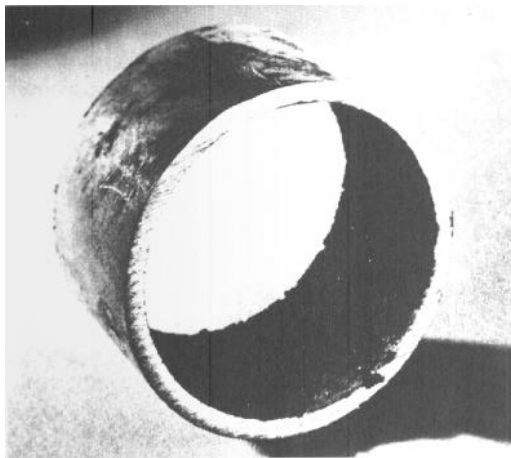
CORROSIVE ATTACK,
DISSOLVED OXYGEN.
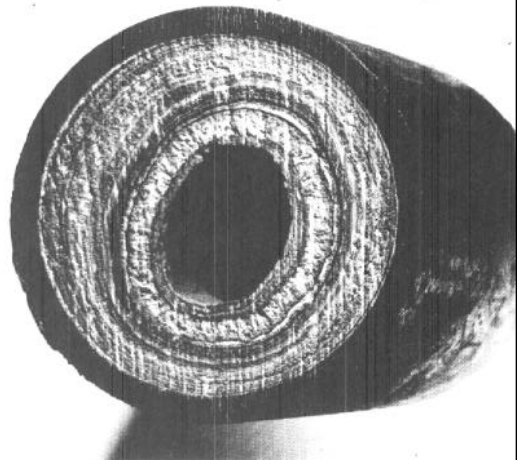
SCALE DEPOSITS
IN WATER LINE.

FIGURE 3-1
Effects of Corrosion and Scale
(Courtesy Betz)

3.2 SOURCES OF WATER. The hydrologic cycle begins with water evaporating from land mass areas and oceans. This moisture precipitates as rain, snow, sleet, or hail. As it falls, it absorbs atmospheric gases (naturally occurring and pollutants) and suspended particles such as dust and smoke. Studies show that these impurities can result in precipitation with a pH range of 3.5 (highly acidic) to 7.1 (neutral). Thus, even rain water is not pure.

3.2.1 Surface Water and Ground Water. Most often fresh water is used for industrial applications. The two most important sources of fresh water are surface water and ground water. A portion of the runoff from rain or melting snow soaks into the ground. Part of it collects in ponds and lakes or runs off into creeks and rivers as surface water. As water flows across the land, minerals are dissolved and the action of the flowing water carries finely divided particles and organic matter in suspension. Roth the character of the terrain and the geology of an area influence the quantity of impurities found in surface water. The portion of water that infiltrates into the earth is ground water. Underground supplies of fresh water differ from surface supplies in two important aspects that can make ground water superior as an industrial water source: relative constant temperature and relative absence of suspended matter. Ground water, however, tends to be higher in mineral content than surface supplies.

3.2.2 Potable Water. Potable water that is commercially processed is also used as a freshwater source. This water, typically obtained from a municipal facility, is treated much differently than industrial use water to assure biological purity and to meet drinking water quality standards. Although pure enough to drink, it usually requires treatment before it is used in industrial processes or systems.

3.2.3 Recycled Water. In many areas, availability of new intake water is limited. Facilities requiring large amounts of process and cooling water find it necessary to conserve available supplies by recycling. Use of effluent streams from sewage treatment plants is a common practice.

3.2.4 Sea Water. The use of sea water is limited chiefly to cooling applications. Facilities located in coastal zones that have large cooling water requirements frequently use sea water. Users should be aware of restrictions on thermal pollution by waste water discharged into streams, lakes, and oceans.

3.3 IMPURITIES IN WATER. Water always is more than a simple combination of hydrogen and oxygen; it contains impurities. The Mississippi River, for instance, carries about 400 million tons of suspended material, and a huge amount of dissolved material, per year to the Gulf of Mexico. The water in the Great Salt Lake contains about 23 percent dissolved material, compared to sea water with 3.5 percent. Table 3-1 lists many of the problems caused by impurities in water.

Solid Impurities. Water in nature always contains both suspended and dissolved solids.

TABLE 3-1

Problems Caused by Water Impurities
(Courtesy Betz Laboratories)

Constituent	Chemical Formula	Problems	Means of Treatment
Turbidity	None-expressed in analysis as units.	Imparts unsightly appearance to water. Deposits in water lines, process equipment, etc. Interferes with most processuses.	Coagulation, settling and filtration.
Color	None-expressed in analysis as units.	May cause foaming in boilers. Hinders precipitation methods such as iron removal and softening. Can stain product in process use.	Coagulation and filtration. Chlorination. Adsorption by activated carbon
Hardness	Calcium and magnesium salts expressed as $CACO_3$	Chief source of scale in heat exchange equipment, boilers, pipe lines, etc. Forms curds with soap. Interferes with dyeing, etc.	Softening. Ion exchange. Internal boiler water treatment. Surface active agents.
Akalinity	Bicarbonate (HCO_3) carbonate (CO_3), and hydroxide (OH) expressed as $CaCO_3$	Foaming and carryover of solids with steam. Embrittlement of boiler steel. Bicarbonate and carbonate produce CO_2 in steam, a source of corrosion in condensate lines.	Lime and lime-soda softening. Acid treatment. Hydrogen zeolite softening. Ion exchange. Dealkalization by anion exchange.
Free mineral acid	H_2SO_4, HCL, etc., expressed as $CaCO_3$	Corrosion.	Neutralization with bases.
Carbon Dioxide	CO_2	Corrosion in water lines particularly steam and condensate lines.	Aeration. Deaeration. Neutralization with bases.

TABLE 3-1

Problems Caused by Water Impurities (continued)
(Courtesy Betz Laboratories)

Constituent	Chemical Formula	Problems	Means of Treatment
pH	Hydrogen ion concentration defined as: $pH = \dfrac{-\log 1}{(H^+)}$	pH varies according to acidic or alkaline solids in water. Most natural waters have a pH of 6.0 to 8.0	pH can be increased by alkalies and decreased by acids.
Sulfate	$(SO_4)^-$	Adds to solids content of water but, in itself, is not usually significant. Combines with calcium to form calcium sulfate scale.	Ion Exchange.
Chloride	Cl^-	Adds to solids content and increases corrosive character of water.	Ion Exchange.
Nitrate	$(NO_3)^-$	Adds to solids content, but is not usually significant industrially. Useful for control of boiler metal embrittlement.	Ion Exchange.
Fluoride	F^-	Not usually significant industrially.	Adsorption with magnesium hydroxide, calcium, phosphate or bone black. Alum coagulation.
Silica	SiO_2	Scale in boilers and cooling water systems. Insoluble turbine blade deposits due to silica vaporization.	Hot process removal with magnesium salts. Adsorption by highly basic anion exchange resins, in conjunction with ion exchange Removed by Bureau of Mines $(PO_4)^{-3}$ treatment.

TABLE 3-1

Problems Caused by Water Impurities (continued)
(Courtesy Betz Laboratories)

Constituent	Chemical Formula	Problems	Means of Treatment
Iron	Fe^{++} (ferrous) Fe^{+++} (ferric)	Discolors water on precip-itation. Source of deposits in water lines, boilers, etc. Interferes with dyeing, tanning papermaking etc.	Aeration. Coagulation and filtration. Lime softening. Cation exchange. Contact filtration. Surface-active agents for iron retention.
Manganese	Mn^{++}	Same as iron.	Same as iron.
Oxygen	O_2	Corrosion of water lines, heat exchange equipment, boilers, return lines, etc.	Deaeration. Sodium sulfite. Corrosion inhibitors. Hydrazine.
Hydrogen sulfide	H_2S	Cause of "rotten egg" odor. Corrosion.	Aeration. Chlorination Highly basic anion-exchange.
Ammonia	$NH3$	Corrosion of copper and zinc alloys by formation of complex soluble ion.	Cation exchange with hydrogen zeolite. Chlorination. Deaeration.
Dissolved solids	None	Dissolved solids is the measure of total amount of dissolved matter, determined by evaporation. High concentrations of dissolved solids are object-ionable because of process interference and are a cause of foaming in boilers.	Various processes, such as split stream, partial cold line, hot lime-soda/zeolite or demineralization will reduce dissolved solids.

TABLE 3-1

Problems Caused by Water Impurities (continued)
(Courtesy Betz Laboratories)

Constituent	Chemical Formula	Problems	Means of Treatment
Settleable solids	None	Settleable solids is the measure of undissolved matter, determined volmetrically. Settleable solids cause erosion of pumps and seals, boilers, water lines, etc.	Subsidence. Filtration.
Suspended solids	None	Suspended solids is the measure of undissolved matter, determined gravimetrically. Suspended solids cause deposits in heat exchange equipment, boilers, water lines, etc.	Subsidence. Filtration, usually preceded by coagulation and settling.
Total solids	None	Total solids is the sum of dissolved and suspended solids, determined gravimetrically.	See dissolved solids and suspended solids.

Suspended Solids. Suspended solids, such as silt, can be removed from water by settling, but only when the water can be allowed to stand quietly for a prolonged period of time. Since settling is seldom practical, most suspended solids are removed by filtration.

Settleable Solids. Settleable solids, such as sand and rust, can be removed from water after a brief (one hour) settling period.

Dissolved Solids. Dissolved solids cannot be removed by simple filtration. These materials are mostly calcium, magnesium, and sodium cations and chloride, bicarbonate, and sulfate anions. Other inorganic soluble solids such as silicates, nitrates, and nitrites are found in lesser amounts. Organic substances may also be dissolved in water. These may be substances leached from natural debris, or introduced through industrial waste and sewage. Some common dissolved solids are:

- Calcium and Magnesium Salts: Calcium and magnesium are the primary salts contributing to water hardness. Calcium salts, usually present as bicarbonate, change to calcium carbonate when water is heated. This forms scale on heat transfer surfaces and reduces efficiency. Calcium sulfate is also present in most natural waters and is another source of scale. Magnesium salts are less important scale formers.

- Alkalinity: Alkalinity, the acid neutralizing power of water, is associated primarily with salts of sodium, calcium, and magnesium in combination with bicarbonate, carbonate, and hydroxyl anions.

- Chloride: The chloride ion is one of several anions found in water and is frequently used to determine the concentration cycles of cooling water. The ratio of chlorides in tower water to chlorides in makeup water is equal to the system concentration cycle, unless heavy chlorination is practiced. Note: Low levels of chloride in the makeup water (e.g < 4 mg/L) can cause an erroneous calculation due to the accuracy of the lower limit of many tests for chloride ions.

- Sulfate: Sulfate ions are common constituents of natural water because of the high incidence of combined sulfur in rocks. Runoff water from mines and industry increases sulfate concentration in surface waters. In industrial cooling water, calcium and sulfate ions are generally maintained at levels below that necessary for calcium sulfate (gypsum) scale formation. Waters drawn from limestone formations are high in calcium carbonate and calcium sulfate scale can form if the water is treated with sulfuric acid for pH adjustment.

Careful control may be required when treating with sulfuric acid to prevent sulfate scale formation.

- Iron: When iron is present in cooling water, it may be a natural constituent, a product of corrosion, or a combination of both. Iron occurs as ferrous bicarbonate in well water and precipitates in the insoluble ferric form when aerated. Deposits resulting from this precipitation are recognized by a characteristic brown color. Certain bacteria use iron in their metabolic process and produce unfavorable iron deposits.

- Manganese: Manganese does not usually cause problems, though it occasionally occurs in water handling systems in the form of dense, black deposits. Where iron oxidizing bacteria exist, some manganese is often deposited.

- Silica: Silica is found in varying concentrations in most water. Water with high silica content usually has high alkalinity and low to medium hardness. Silica scale occurrence is generally confined to the arid areas where water supplies often have high silica content.

3.3.1 Gas Impurities. Natural waters contain dissolved gases. Some of the more common gases and their effects on water are as follows:

- Carbon Dioxide: Carbon dioxide is soluble in water and combines with water to form carbonic acid. Carbon dioxide accelerates the solvent effect of groundwater and contributes to hardness by dissolving limestone and other rocks. Acidity is directly related to carbon dioxide concentration.

- Dissolved Oxygen: The amount of dissolved oxygen in water is directly related to temperature and pressure. Dissolved oxygen in water acts as a cathodic depolarizer, promoting corrosion.

- Hydrogen Sulfide: Some well water contains hydrogen sulfide that can be released by aeration; the degree of release attainable depends on the pH of the water. More complete removal is attained at lower pH levels than at higher pH levels. Water containing hydrogen sulfide is commonly called sulfur water and has the odor of rotten eggs.

3.3.2 Biological Impurities. All water contains some biological activity. When organisms are present in great numbers, the chemical composition of the water may be so altered that radical changes in methods of operation or treatment procedures are necessary. Organisms frequently cause fouling of heat transfer surfaces and clogged filters.

3.4 TERMINOLOGY AND MEASUREMENT. There are many terms commonly used for describing water quality, and there are typical units used for expressing these terms. Those most commonly used are described here.

3.4.1 Parts Per Million. In reporting results of an analysis where a material is reduced to its constituents, it is typical to express the quantity of each constituent per 100 parts of material. This gives values in percent. For example, in analysis of an alloy, if the chemist reports a 60 percent copper content, it would mean that for each 100 parts of alloy, 60 parts of copper are present. Reporting by percent is awkward in water analysis since the amount of materials present is usually extremely small. For example, if the silica content of natural water is expressed in percent, values would range from 0.0001 percent to 0.01 percent. To avoid use of unwieldy decimals and to prevent loss of significant figures,, parts per million (ppm) is usually used in water analysis. Thus, the above percentage range would be 1 ppm to 100 ppm One part per million equals one part of a constituent in one million parts of solution. For example, if a water sample contains 1 ppm silica, there would be 1 pound of silica in 1,000,000 pounds of water. Expressing results in terms of parts per million allows results to be reported in whole numbers.

3.4.2 Grains Per Gallon. A second unit of measurement is grains per gallon. The significance of this expression is less obvious than parts per million. There is a simple relationship between the weight in grains of the substance being reported and the weight of a gallon of water, since 1 pound equals 7,000 grains. For conversion purposes, 1 grain per gallon equals 17.15 parts per million. This expression of measurement is principally used for resin capacity, but rarely elsewhere.

3.4.3 Equivalents Per Million. A third unit of measurement is equivalents per million (epm). This unit is often preferred by water technologists since its calculation is simple. Results in equivalents per million are obtained by dividing the concentration in parts per million by the chemical combining weight or equivalent weight for each ion or substance. Equivalent weights can be obtained from tables. For example, to convert 25 ppm of chloride to epm:

$$\frac{25 \ ppm}{\text{equivalent atomic weight of chloride}} = \frac{25}{35.5} = 0.71 \ epm$$

3.4.4 pH. pH is a measure of the quantity of hydrogen ions in solution. It is measured on a 0 to 14 scale, with 7 being the neutral point. Adding acid to water lowers pH; addition of alkaline material increases pH. Because the pH scale is logarithmic, each decrease by one unit indicates an increase in hydrogen ions (or intensity of acidity) by a factor of 10. Similarly, an increase of

one full pH unit indicates a tenfold decrease in hydrogen ions. An understanding of pH is important in water treatment. In general, pH ranges below 7 are increasingly corrosive; pH ranges above 7 are more conducive to scale formation. Figure 3-2 is an example of a pH scale showing some approximate values.

3.4.5 Alkalinity. The terms alkalinity and pH are frequently confused. Alkalinity is a measure of the capacity of a solution to buffer decreases in pH. It is generally expressed in parts per million. Depending on the type of dissolved solids, it is possible for several water samples to have a pH of 7.5, but with alkalinities ranging from 50 to 250 ppm. Variation in alkalinity occurs because dissolved solids have different levels of chemical activity. Figure 3-3 shows the relationship between alkalinity, carbon dioxide content, and pH. Carbon dioxide is a factor because it forms carbonic acid when dissolved in water, which affects pH. Note that alkalinity is expressed as parts per million of calcium carbonate, which is the reference standard. If other ions are present, they are converted to calcium carbonate equivalents by use of Table 3-2. The combination of all ions present expressed in terms of $CaCO_3$ gives the "total alkalinity" of the sample.
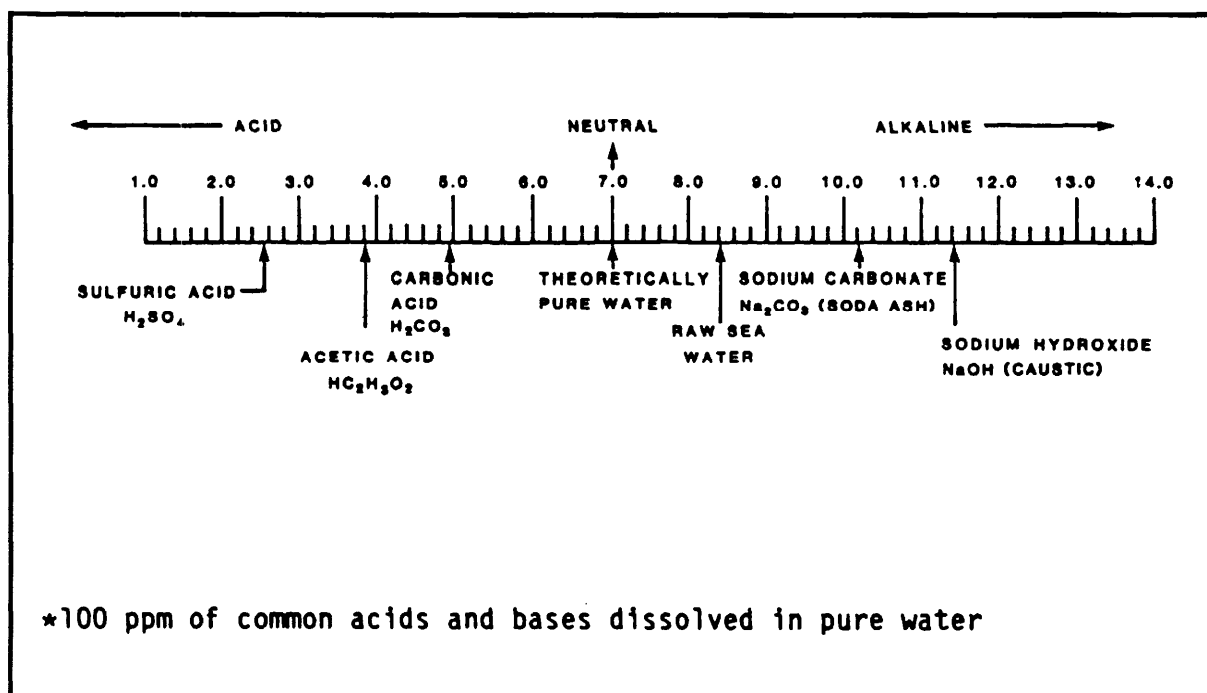
FIGURE 3-2
Approximate pH Values of Common Acids and Bases
(Courtesy Drew Chemical Company)
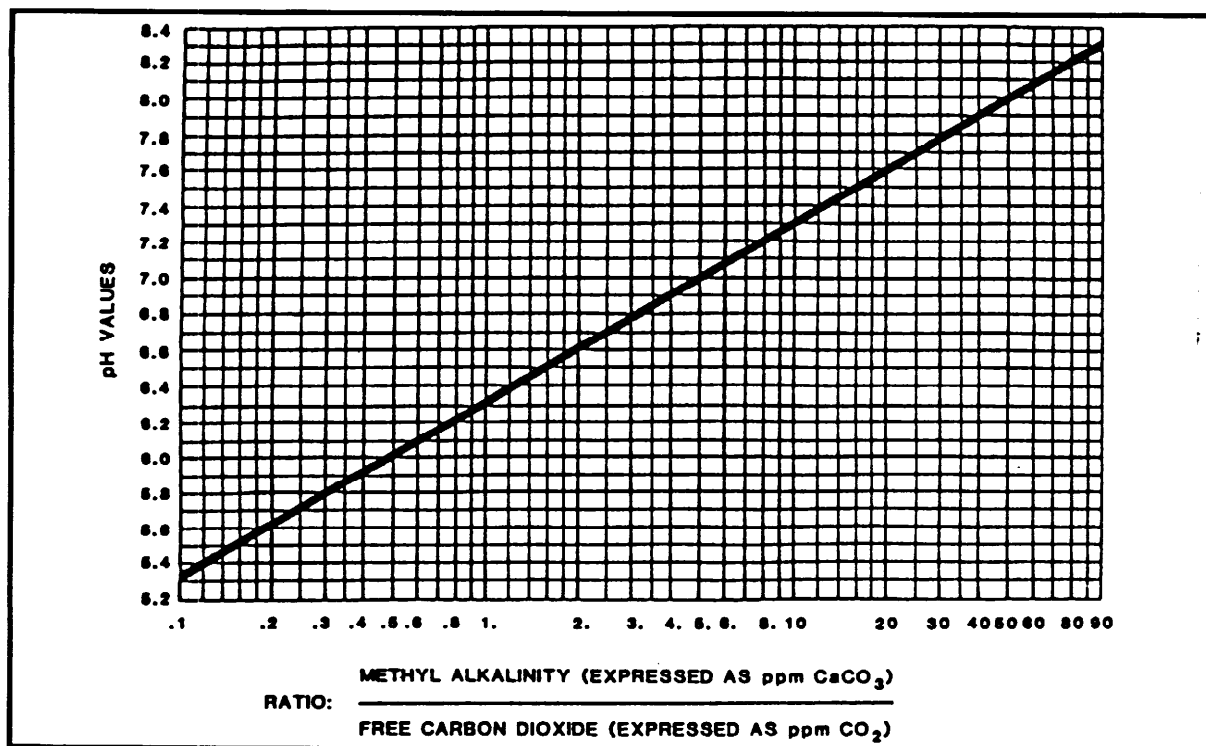
FIGURE 3-3
Relationship Between Alkalinity, Carbon Dioxide, and pH
(Courtesy Drew Chemical Company)

TABLE 3-2

Conversion Factors for Calculating Alkalinity

Ion		Factor			Ion		Factor		
Ca	x	2.5	=	$CaCO_3$	N O$_3$ x		0.81	=	$CaCO_3$
Mg	x	4.1	=	$CaCO_3$	HCO$_3$ x		0.82	=	$CaCO_3$
Na	x	2.18	=	$CaCO_3$	P O$_4$ x		1.56	=	$CaCO_3$
K	x	1.28	=	$CaCO_3$	* C O$_3$ x		0.84	=	$CaCO_3$
S O$_4$ x		1.04	=	$CaCO_3$	* C O$_2$ x		1.14	=	$CaCO_3$
Cl	x	1.41	=	$CaCO_3$	* S i O$_2$ x		0.83	=	$CaCO_3$

*These factors based on sorption as Monovalent Ions.
*For true $CaCO_3$ equivalents, multiply factors by two

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3.4.6 Hardness.   Water hardness is caused by dissolved calcium and magnesium and is a significant factor in over 85 percent of the United States and Canada. Figure 3-4 shows the variation in water hardness in the contiguous U.S. The primary source of water hardness is common limestone (calcium carbonate). Other sources include dolomite (calcium magnesium carbonate), calcium sulfate, magnesium sulfate, and either calcium or magnesium chloride. Water hardness is the chief cause of scale buildup in heat exchange equipment and must be controlled by treatment. Hardness is expressed as parts per million or grains per gallon of calcium carbonate equivalent and is classified as follows:

Classification	Grains Per Gallon	Parts Per Million
Soft or Slightly Hard	0 - 3.5	0 - 60
Moderately Hard	3.5 - 7.0	61 - 120
Hard	7.0 - 10.5	121 - 180
Very Hard	more than 10.5	more than 180

3.4.7 Conductivity and Resistivity.   Water quality is also expressed in terms of conductivity and resistivity. Absolutely pure water contains no impurities and, therefore, has little means to transport electric energy. When ions are added because of impurities, the resulting solution has the ability to conduct electricity in proportion to the number and type of ions. Thus, resistance increases as the impurity level decreases. Electric resistance is defined by Ohm's Law as:

$$Resistance = \frac{Voltage}{Current}$$

Current is expressed in amperes, voltage in volts, and resistance in ohms. Conductance is the inverse, or reciprocal, of resistance and is assigned the unit mho. When corrected for dimensional effects (length divided by cross sectional area), conductance becomes conductivity.
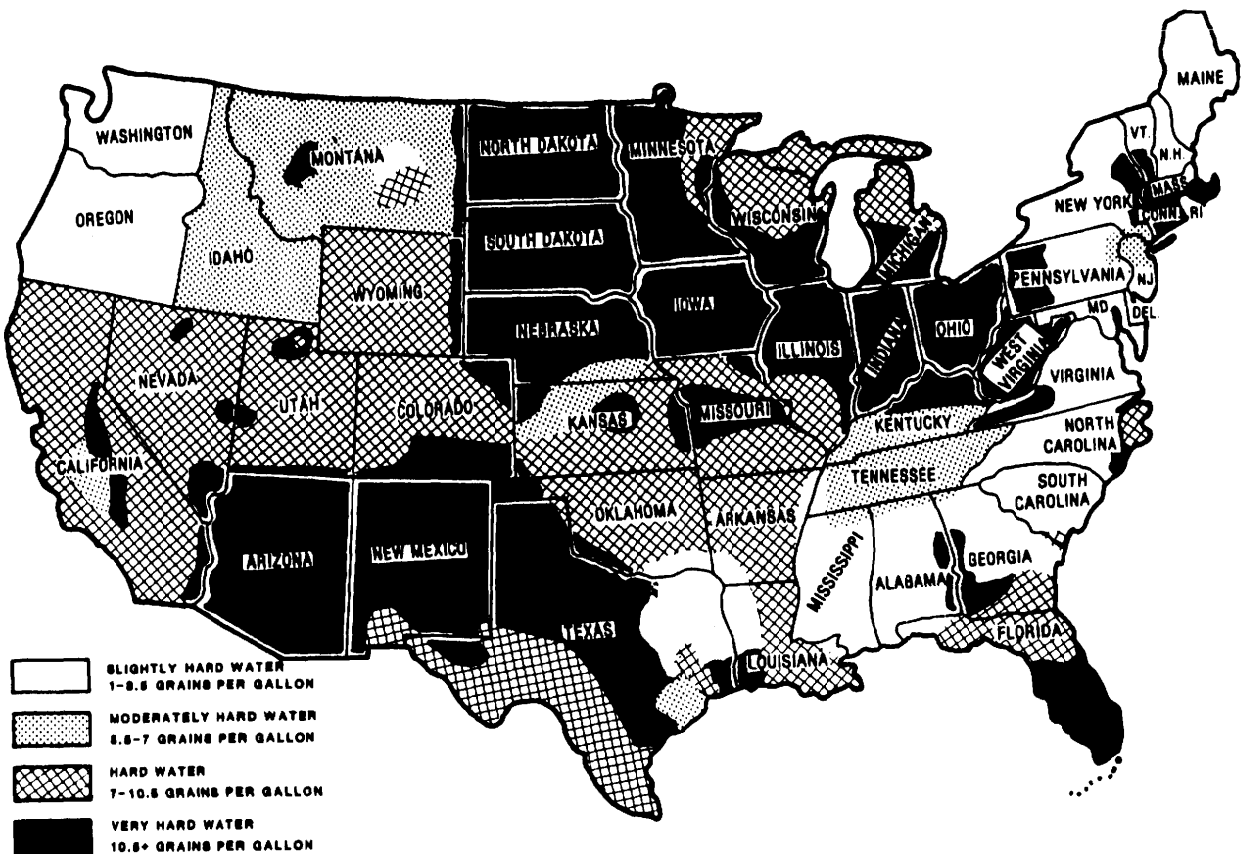
FIGURE 3-4
Water Hardness Throughout the Contiguous United States

3-13

Because conductivity in water is usually a small number, micromhos per centimeter (umho/cm), or one-millionth of a mho measured across 1 centimeter, is generally used. Conductivity increases with the ion concentration in the water.

Figure 3-5 shows a relationship between dissolved solids, resistivity, and conductivity, using an empirical multiplier of 0.5 (i.e., conductivity x 0.5 = TDS). This multiplier is variable, dependent on source water conditions. Table 3-3 shows how resistivity varies with water purity.

3.4.8 Total Dissolved Solids (TDS). All water contains dissolved solids that have been collected from the atmosphere, land, and water. The classification of water by concentration of dissolved solids is as follows:

Description of Waters	Concentration of Dissolved Solids (ppm)
Fresh	0 - 1,000
Brackish	1,000 - 10,000
Salty	10,000 - 100,000
Sea Water	33,000 - 36,000**
Brine*	100,000 +

*As found in the Dead Sea, Great Salt Lake, and brine wells.
**Seawater concentrations are often reported in parts per thousand.
Thus, seawater with a concentration of 33,500 ppm would be reported as 33.5 parts per thousand TDS.

When water is evaporated from a container, dissolved solids are deposited as scale. When water is used in industry, it is generally not boiled to dryness but is subjected to some heating (or cooling). Under these conditions scale forms from the unstable salts of calcium and magnesium present. The presence of scale-forming compounds is known collectively as water hardness. Deposits form because solubility decreases as temperature increases. In addition, the presence of other substances in a water system sometimes increases the rate of scale formation. Table 3-4 illustrates the solubility of some dissolved solids commonly found in water.

Solubility of Solids. When water is heated, bicarbonates of calcium, magnesium, and sodium can decompose into carbonates, carbon dioxide and water. In the case of calcium and magnesium, solubility then decreases and scale deposition occurs. With sodium, however, the solubility is increased and scaling is not a problem. The problem associated with calcium and magnesium salts in scale formation can be immense. For example, a boiler producing 100,000

$$\frac{1,000,000}{\text{OHMS}} = \text{MICROMHOS} \qquad \frac{1,000,000}{\text{MICROMHOS}} = \text{OHMS}$$

APPROXIMATE DISSOLVED SOLIDS - PPM AS $CaCO_3$
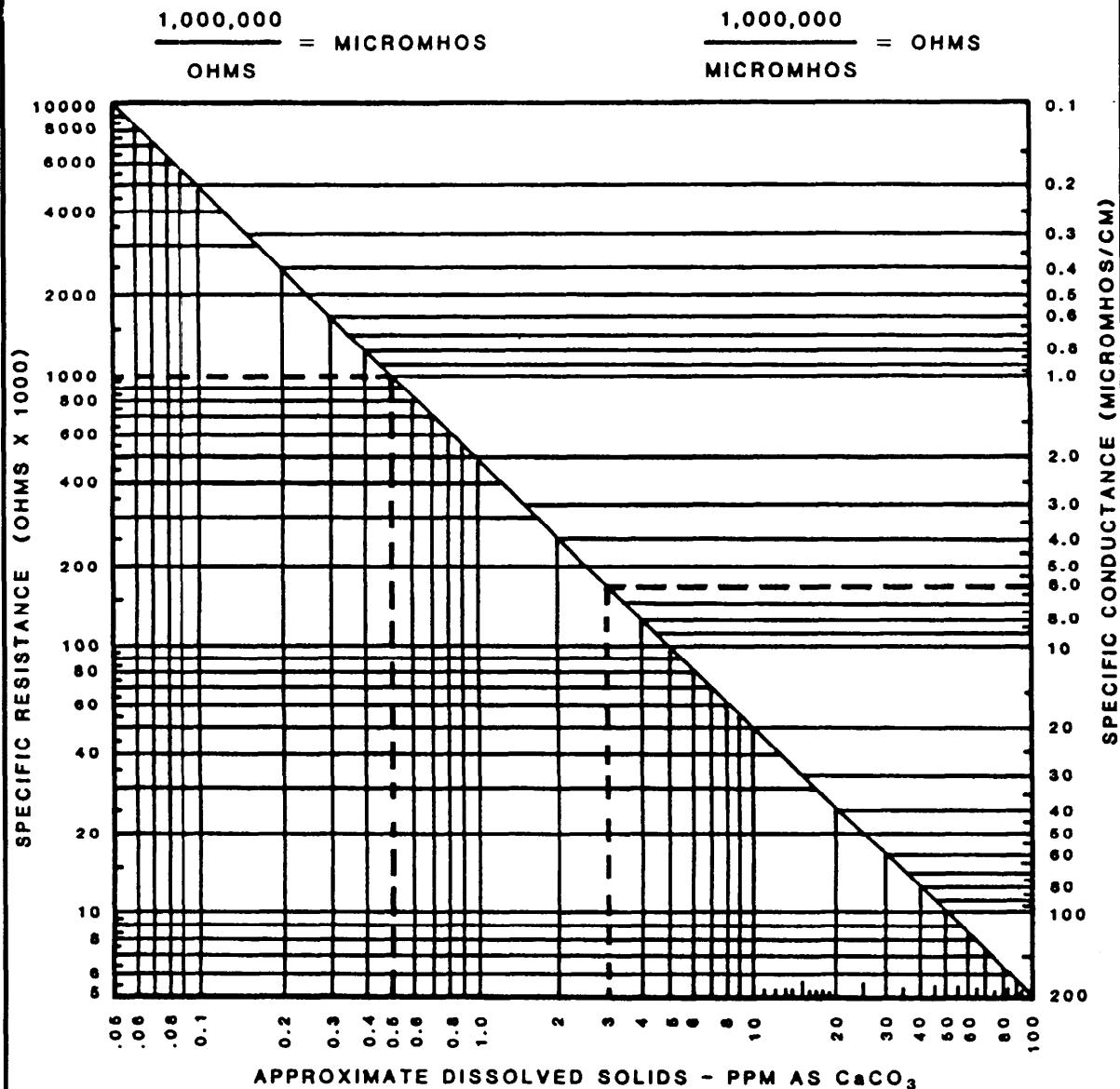
EXAMPLE: If approximate dissolved solids are 3 ppm as $CaCO_3$, then the Specific Conductance is 6.0 micromhos/cm.

EXAMPLE: If approximate dissolved solids are 0.5 ppm as $CaCO_3$, then the Specific Resistance is 1 ohm, since the chart shows ohms x 1000. (1000/1000 = 1 ohm)

FIGURE 3-5
Conversion for Ohms-cm and Microohms/cm
With Approximate Dissolved Solids

3-15

TABLE 3-3

Resistance of Water Obtained From Various Sources

Type of Water	Electrical Resistivity (ohm-cms)	Electrical Conductivity (umho/cm)
Theoretical maximum quality (calculated)	26,000,000	0.038
Water after 23 distillations in quartz	23,000,000	0.043
Water treated in a Monobed resin system (strongly acidic-strongly basic system)	18,000,000	0.055
Water after three distillations in quartz	2,000,000	0.5
Water after three distillation in glass	1,000,000	1.0
Water in equilibrium with the carbon dioxide in the atmosphere	700,000	1.4
Water after a single distillation in glass	500,000	2.0
Approximate quality of U.S.P. distilled water	100,000-500,000	10-2
Navy Requirement		
Condensed steam for ships	40,000	25.0
Demineralized water	400,000	2.5

pounds of steam per hour will use 300,000 gallons of water per day. If un-treated Lake Michigan water (see Figure 3-4) with only moderate hardness (3.5 - 7.0 grains per gallon) is used, about 225 pounds (7,000 grains = 1 pound) of calcium and magnesium salts will enter the boiler each day. On a yearly basis this amounts to over 82,000 pounds of potential scale.

3.5 DETERMINING QUALITY. The requirement for water quality is determined by the end use of the water. Table 3-5 shows results of three water analyses in comparison with the NAVSEA specification for shore-to-ship steam quality. For selected cooling applications, sample A (sea water) may be of sufficient

TABLE 3-4

Solubility in Water (ppm as $CaCO_3$)

Substance	Water Temperature	
	32°F	212°F
calcium		
Bicarbonate	1,620	Decomposes to carbonate
Carbonate	15	13
Magnesium		
Bicarbonate	37,000	Decomposes to carbonate
Carbonate	101	75
Sodium		
Bicarbonate	38,700	Decomposes to carbonate
Carbonate	61,400	290,000

TABLE 3-5

Comparison of Water Quality

Constituent	Water Samples			
	A	B	C	D
pH	7.5 - 8.4	7.2 - 8.7	11.0 - 11.1	8.0 - 9.5
Conductivity (umhos/cm)	12,000	40-300	885-890	25 Max
Dissolved silica (ppm)	10	2.3 - 11.1	0.4 - 1.4	0.2 Max
Hardness (ppm)	6,250	15 - 132	2	5.0 Max
Tot al Dissolved Solids (ppm)	34,450	35-205	619 - 710	No requiremen

Key:
A. Sea water
B. Municipal water supplies for naval base (1982) quality. Sample B, taken from a municipal water supply, may be suitable for heat exchangers and human consumption.
C. Condensate from shore steam headers at naval base supplying steam to ships (1982)
D. NAVSEA requirement for shore-to-ship steam purity

Sample C, taken from a condensate return main, is of sufficient quality for boiler feedwater. Sample C, however, falls far short of purity requirements specified by NAVSEA for steam piped to ships. The NAVSEA specification is necessarily strict because condensate is collected by the shipboard boiler system for reuse. Most shipboard boilers operate at high pressure, making high quality water mandatory.

3.6 CORROSIVITY. One important measure of corrosivity of water is a factor known as the calcium carbonate saturation index. In many cases, there is insufficient information to indicate whether scale will form and whether it will be dense, uniform, or protective. Flow characteristics of a system tend to influence both the amount of scale that develops and the uniformity of the deposit. In practice, indications are that scale will start to deposit at slightly supersaturated conditions, depending on pH. This can lead to increased frictional resistance, clogging of valves and controls, and decreased heat transfer rates in water heaters and 'boilers. In addition, water that has undesirable properties at room temperature may become inoffensive when heated.

3.7 RYZNAR STABILITY INDEX. A method for predicting scaling tendencies of water has been developed and is called the Ryznar Stability Index. This index is calculated by subtracting the actual pH value from the doubled pH of saturation or pHs. The pHs is calculated from the calcium content, alkalinity, total dissolved solids and temperature of a solution. The Ryznar Stability Index is often used to improve accuracy in predicting scaling or corrosion tendencies and the following chart illustrates this relationship.

Ryznar Stability Index	Tendency of Water
4.0 - 5.0	heavy scale
5.0 - 6.0	light scale
6.0 - 7.0	little scale or corrosion
7.0 - 7.5	corrosion significant
7.5 - 9.0	heavy corrosion
9.0 and higher	corrosion intolerable

CHAPTER 4. FEEDWATER

4.1 PRELIMINARY TREATMENT. The type of water treatment required for a given industrial water application is primarily a function of the quality of the raw water source. In most cases, potable water from the local utility or military reservation water supply is employed. In such cases, there is little if any requirement for pretreatment.

Pretreatment is defined as the processes involved in modifying the physical and/or chemical characteristics of a water to make it suitable to be used as makeup for the treatment system servicing a boiler, cooling tower or other mechanical device. The most common pretreatment processes are aeration, clarification and filtration.

Pretreatment is usually associated with the use of non-potable water from surface water or wastewater sources. The most frequent use of non-potable water is for large cooling water requirements.

Close scrutiny should be employed in reviewing the suitability of a non-potable water source for any mechanical system. The physical and chemical characteristics of gray water from industrial and sanitary sewage treatment plants often vary significantly from day to day. As a consequence, a brief testing period for the effluent of a wastewater treatment plant or a small stream may generate erroneous conclusions on their suitability as a heat sink medium.

The subject of types of pretreatment systems along with their limitations will not be addressed in this document. For a detailed discussion on these systems refer to the following references. This is not an endorsement as to the accuracy of these texts. Rather, this listing is provided merely as an assistance to the reader.

> The NALCO Water Handbook
> NALCO CHEMICAL COMPANY
> Frank N. Kemmer, Editor
> McGraw-Hill Book Company, 1979
>
> DREW Principles of Industrial Water Treatment
> The DREW CHEMICAL COMPANY
> Division Ashland Oil Company
> One Drew Plaza
> Boonton, New Jersey 07005

4.2 PURIFICATION METHODS. The purpose of using purification methods to remove or modify dissolved solids and gases in water is to prevent scale and corrosion. The general techniques are chemo-mechanical, ionic manipulation, or some combination of both. Methods discussed are as follows:

- Deaeration
- Evaporation.
- Lime, Hot or Cold.
- Electrodialysis.
- Membrane Separation.
- Ion Exchange.
- Softening/Dealkalization.
- Demineralization.

The type of treatment selected is dependent on the end use of the water. The cost of treatment methods varies greatly. To achieve the desired result at a practical cost, several processes may be operated in parallel, or more commonly, in series. Table 4-1 summarizes results attainable by various methods of treatment.

4.2.1 Deaeration. Water containing dissolved gases causes many corrosion problems. Oxygen in water produces pitting that is particularly severe because of its localized nature. Carbon dioxide corrosion is frequently encountered in condensate systems and, less commonly, in water distribution systems. Water containing ammonia readily attacks copper and copper-bearing alloys. Deaeration is widely used for removing dissolved gases from water to control corrosion. In particular, it is used to remove oxygen and carbon dioxide from boiler feedwater systems. While conventional power plant deaerators remove many dissolved gases from water, they frequently do not remove the large quantities of dissolved gas found in many industrial plant waste streams. Vacuum deaeration has been used sucessfully in water distribution systems, but pressure deaeration, with steam used as purge gas, typically is employed to deaerate boiler feedwater. Steam is chosen as the purge gas because it is readily available; it heats the water and reduces the solubility of oxygen and carbon dioxide; and it does not contaminate the water. Only a small quantity of steam need be vented, because most of the steam used is condensed into the deaerated water. Boiler feedwater is deaerated by spraying the water into a steam atmosphere. This heats the water to within a few degrees of the temperature of the

TABLE 4-1

Results Attainable by Various Water Treatment Processes for Boiler Applications

Boiler Pressure (psi)	Treatment Process	Resultant Feedwater (ppm)			
		Total Hardness	Alkalinity	Silica	Total Solids
0 - 300	Sodium zeolite	0-2	No change	No change	No change
	Splitstream softening	0-2	15-20	No change	Reduced with alkalinity
	Sodium zeolite/ chloride anion dealkalization	0-2	10% raw water	No change	No change
	Hat process softening	10-20	40-60	1-2	Reduced with alkalinity
300 - 900	Hot process/hot zeolite	0-0.1	20-40	1-2	Reduced with alkalinity
	Demineralization	0-0.1	0-5	0-1.0	0-5
900 and above	Demineralization	0-0.1	0-5	0-0.1	0-5
	Evaporation	0-0.5	0-10	0-0.1	0-10

saturated steam. Since solubility of oxygen in water is very low under these conditions, 90 to 95 percent of the oxygen in the incoming water is released and purged from the system by venting. The remaining oxygen is not soluble under equilibrium conditions and is not readily released. Therefore, water leaving the heating section of the deaerator must be vigorously scrubbed with steam to remove the last traces of oxygen. Some gases are not as easily removed from water as oxygen. Ammonia is most efficiently removed at alkaline pH levels

since only the ammonium hydroxide form exerts a gas solution pressure that permits ammonia to be removed by deaeration. With the best ammonia removal achieved at a high pH, and the best carbon dioxide removal at a low pH, complete degasification of a stream containing a combination of the two is difficult to achieve by deaeration.

Deaerators. Pressurized deaerating heaters increase feedwater temperature by direct contact with exhaust steam and remove undesirable dissolved gases. Two major types are the tray type and the spray type.

Tray Type. In a tray type deaerator, a water spray is directed to fall freely over baffle trays (Figure 4-1). Steam is condensed within the heater bringing the water up to saturation temperature. Steam scrubs the dissolved gases from the feedwater. Non-condensable gasses along with a small amount of steam escape the unit through a vent. Inspections should be made regularly to see that trays are free of deposits and in proper alignment and that openings in the distributor pipe or nozzles are clear of any obstructions.

Spray Type. Spray type deaerators work on the same general principles as the tray type. Water is sprayed into a plenum by spring loaded nozzles located in the top section. Direct contact heating and primary deaeration take place in the plenum. This first stage spray may function as a condenser with the vent located in the center of the spray pattern. Secondary deaeration can take place in a second spray valve, an atomizing weir, or by passing all incoming steam through trays. Spray nozzles should be kept free of dirt and corrosion, otherwise improper atomization will prevent deoxygenation.

Deaerating Condensers. In central stations, main turbine condensers have air ejectors that remove dissolved gases. Sometimes, because enough deaeration is obtained from these condensers, the pressure deaerator is omitted from the feedwater cycle. Since there is a danger of air leaking into the system, both during start-up and while condensers are operating at low loads, pressure deaerators are included in many central station designs.

Vacuum Deaeration. Vacuum deaeration is used for deaerating water at temperatures below the atmospheric boiling point to reduce the corrosion rate in water distribution systems. Like the pressure deaerator, the vacuum deaerator is designed to bring water to its saturation temperature by applying a vacuum to the system rather than heating the water. It then divides the water into small particles to facilitate gas removal, which is vented from the unit.

Applications and Advantages. Pressure deaerators, used to prepare boiler feedwater, produce deaerated water that is very low in both dissolved oxygen and

4-4
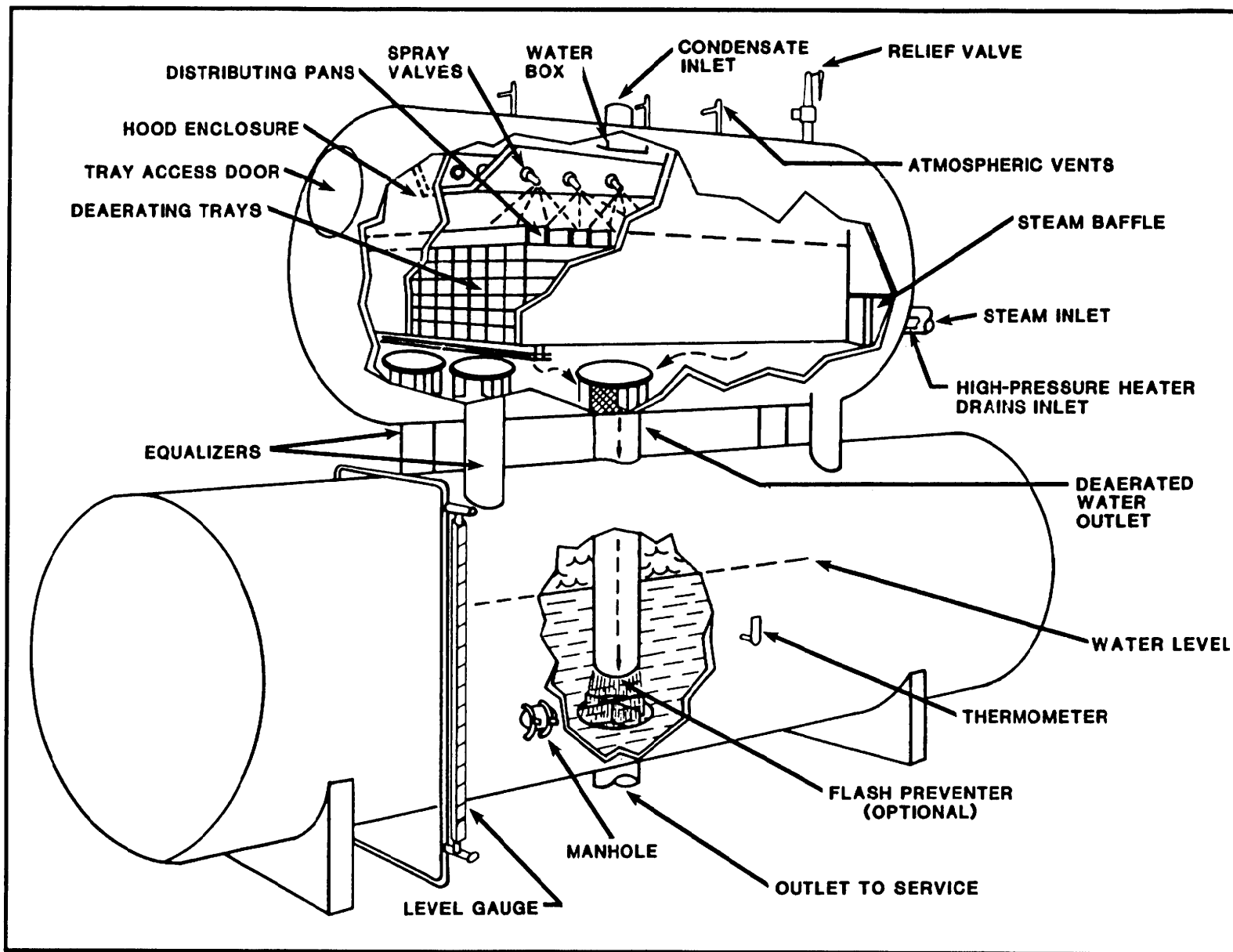
FIGURE 4-1
Tray Type Deaerating Heater
(Courtesy Betz)

DISTRIBUTING PANS
SPRAY VALVES
WATER BOX
CONDENSATE INLET
RELIEF VALVE
HOOD ENCLOSURE
TRAY ACCESS DOOR
DEAERATING TRAYS
ATMOSPHERIC VENTS
STEAM BAFFLE
STEAM INLET
HIGH-PRESSURE HEATER DRAINS INLET
EQUALIZERS
DEAERATED WATER OUTLET
WATER LEVEL
THERMOMETER
FLASH PREVENTER (OPTIONAL)
MANHOLE
OUTLET TO SERVICE
LEVEL GAUGE

4-5

free carbon dioxide. Vendors usually guarantee less than 0.005 cubic centimeters (cc) per liter of oxygen and zero free carbon dioxide whenever bicarbonate alkalinity exceeds 5 ppm. Vacuum deaerators, used to protect water distribution lines, are not designed to provide deaeration that is as complete as pressure deaerators. They will usually reduce dissolved oxygen to a range of 0.25 to 0.50 cc per liter. Deaerators function efficiently with minimum maintenance and usually are economical to operate.

Limitations. Inlet water to deaerators should be free of suspended solids that can clog spray valves and ports of the inlet distributor and deaerator trays. In addition, spray valves, ports, and deaerator trays may plug with scale that forms when water being deaerated has high hardness and alkalinity levels. While pressure deaerators reduce oxygen to low levels, even trace amounts of oxygen may cause corrosion damage to a system.

Consequently, good operating practice requires removal of the last traces of oxygen with a chemical scavenger such as sodium sulfite or hydrazine.

The differences between the usage of catalyzed sodium sulfite vs. hydrazine for oxygen scavenging are quite extensive. The governing chemical reactions are detailed below:

$$2\,Na_2SO_3 + O_2 = 2\,Na_2SO_4$$

sodium sulfite $\qquad$ oxygen $\qquad\qquad$ sodium sulfate

$$N_2H_4 + O_2 = 2\,H_2O + N_2$$

hydrazine $\qquad$ oxygen $\qquad\qquad$ water $\qquad$ nitrogen
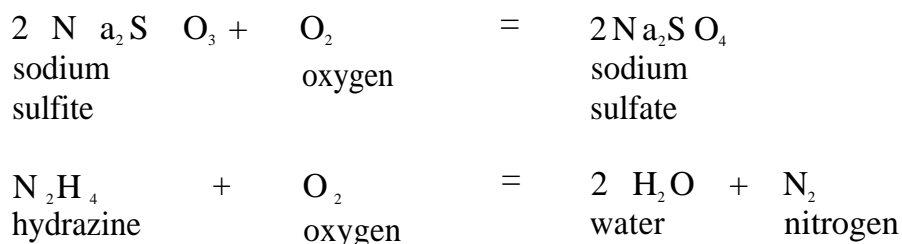
The reactants of the two equations are different in that the reactant sodium sulfate is a precipitating solid while the reactants from hydrazine are only nitrogen gas and water. Thus, the use of sodium sulfite imparts an increase in the dissolved solids loading of the boiler.

Because of the toxic nature and handling difficulties of hydrazine, it should only be used in high pressure boilers operating above 600 psi. At these higher pressures, sodium sulfite decomposes to form sulfur dioxide and hydrogen sulfide. Both of these gases can be quite corrosive to the condensate return piping. For lower pressure boilers, hydrazine should not be used unless specific permission is obtained from the safety officer, environmental officer, or other responsible individual. Further, the limitation of zero hydrazine for steam in contact with food, direct steam humidification systems, and hospital instrument sterilization

must always be attained. These regulations are referenced on page 5-47 of this document.

Free carbon dioxide can be removed by deaeration, but the process releases only small amounts of combined carbon dioxide. The majority of the combined carbon dioxide is released with steam in the boiler and subsequently dissolves in the condensate, causing corrosion problems.

In the past few years, there have been several catastrophic failures of deaerators in service at a variety of locations in North America. The fatalities from some of these failures stemmed from the mechanism of fractures of the pressure vessel walls. The deaerator walls completely separated and did not merely leak.

Inspections of older (20 + years) deaerators should be accomplished on an annual basis. The vessel walls and welds should be checked for crack propagation by visual, ultrasonic and wet fluorescent magnetic particle procedures.

Metallurgical examination of cracks on deaerators indicates a mixed mode of mechanisms contributing to these failures. Corrosion fatigue and stress induced corrosion are indicated at residual stress and weld areas. Remedial procedures include grinding and welding the cracks. Thermal stress relieving of the weld repairs is helpful, but coatings have been found to offer very little benefit.

     4.2.2 Evaporation.   Evaporation is used to remove solids. There are many types of evaporators, and several factors govern their selection. These include ease of operation, control of scale formation, accessibility for cleaning and required purity of vapor. Evaporator systems are commonly employed aboard ships. In an evaporation system, water to be treated is heated in a chamber and converted to vapor, leaving behind impurities in the unvaporized water. The vapor is then condensed to a liquid. The source of heat used to vaporize the water typically is either high- or low-pressure steam. A simple schematic of an evaporator system is shown in Figure 4-2. The evaporation process can occur at any temperature corresponding to the boiling point of water at the pressure in the chamber. Accordingly, some evaporators operate below 212°F, the sea level boiling point of water. Because evaporators require large amounts of energy to operate, they are less popular; however, they are still in use. Several types of evaporators are available. They are classified as submerged tube, film, flash, and compression distillation. They are designated as single-, double-, or multiple-effect. An evaporator that consists of a single heating chamber is a single-effect evaporator. For economy, it may be desirable to place a number of units in series. The units are then called multiple-effect evaporators. Where a double effect arrangement is used, vapor from one effect is used to heat and vaporize water in the next effect in the series. Vapor coils of each effect then serve as the
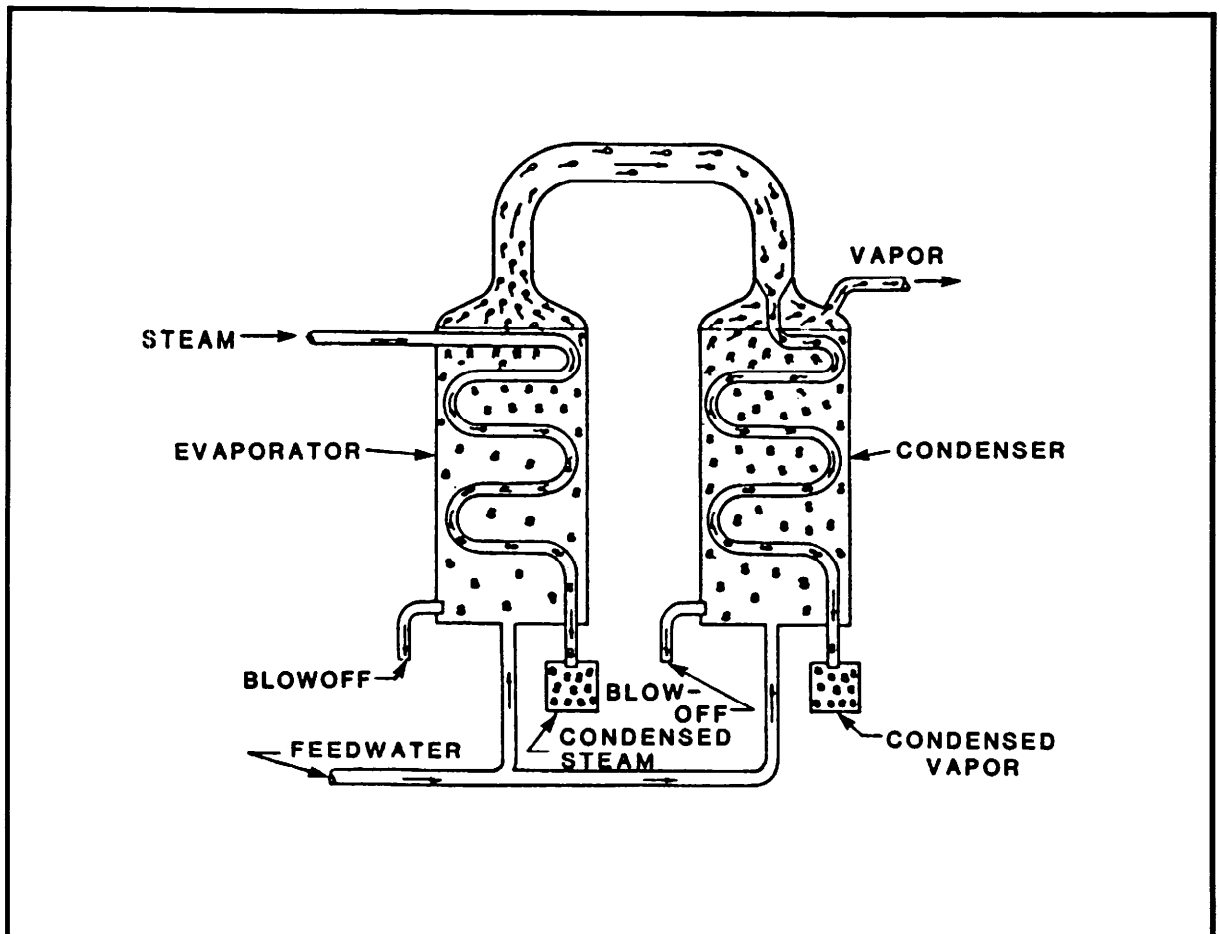
FIGURE 4-2
Evaporator System

condenser for the previous effect. By using the vapor from each prior effect, the efficiency of the apparatus is increased with respect to the amount of primary steam required to evaporate a given amount of water.

Evaporator Economy and Performance. The amount of distilled water produced by an evaporator per pound of steam used is the evaporator economy. Single-effect evaporators will deliver about 0.9 pounds of distillate per pound of steam. Typical evaporator performance for multiple-effect units is as follows:

Ratio of Pounds of Steam Supplied/Pounds of Distillate Produced

Single-effect evaporator	1/0.9
Double-effect evaporator	1/1.65
Triple-effect evaporator	1/2.3
Quadruple-effect evaporator	1/2.8

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Evaporators may be obtained with performance guaranteed to produce a distillate that contains no more than 0.5 ppm total solids when fresh water is used for evaporator feed. If sea water is used as feed, the guarantee may warrant that distillate will contain no more than 0.25 grains (4.0 ppm) of total salts per gallon. Carryover from an evaporator, similar to carryover from any low-pressure boiler, consists of vapor in which shell water is either chemically or mechanically entrained. The concentration of shell water is, perhaps, the most important influence on vapor purity. A limiting concentration may be specified by the evaporator manufacturer. Antifoam agents may be used to improve steam purity the same way they are used in boilers. Depending on characteristics of the feedwater, chemical treatment may be needed to prevent scale formation.

Pretreatment of Raw Water to Evaporators. Raw water containing high concentrations of solids can be fed directly to evaporators, but performance and maintenance can be improved by pretreatment. Pretreatment by sodium zeolite softeners eliminates practically all scale-forming solids from the evaporator, even though total soluble solids concentration is somewhat greater after treatment than before.

Deaeration of Feedwater to Evaporators. Deaeration of feedwater to evaporators is desirable for reducing corrosion in the evaporator and condensate lines. Oxygen can be eliminated and free carbon dioxide reduced to low levels. Carbon dioxide carried over with vapor is dissolved when the vapor is condensed and, because the condensed liquid contains few buffering solids, the water can be aggressive.

Scale Problems. Evaporator capacity tends to fall as scale deposits on tubes. In practice, units operating on sea water require scale removed every 300 to 700 hours. With fresh water, this period is extended to as much as 2,000 or 3,000 hours. In some cases, evaporators are designed for cold shock treatment. When the evaporator is shut down but still hot, cold water is sprayed on the hot tubes. Rapid temperature change causes tubes to contract suddenly and adherent hard scale cracks off.

4.2.3 <u>Lime--Hot or Cold.</u> Use of lime to remove hardness is probably the oldest chemical process for water treatment. The first plants built for this type of treatment were merely large tanks where hard water was mixed with lime water. The mixture was allowed to stand and precipitates formed and settled. Clear water was decanted by a swing pipe and filtered. Similar equipment, though slightly modified, is used for batch softening today.

Cold Lime Process. In the cold lime/soda process, certain impurities are removed from water by chemical precipitation. Chemicals are added that form

insoluble compounds, which are allowed to settle. The relatively clear, settled water is filtered to remove the last traces of solid matter. The lime/soda process serves two purposes, removal of hardness and reduction of alkalinity. Even though some silica reduction occurs in cold lime processes from interaction of temperature, sludge contact, and presence of magnesium hydroxide precipitates, cold lime should not be relied upon as an effective means of silica reduction. A modification of the cold lime process, called "warm" lime, is used to increase silica reduction. Warm lime requires magnesium oxide be added to preheated (120°-150°) water. In the cold lime process three reactions take place as follows:

- Calcium hardness is converted into insoluble calcium carbonate (limestone).

- Magnesium hardness is converted into magnesium hydroxide.

- Alkalinity reduction is obtained.

The cold batch process to a large extent, has been supplanted by the hot continuous process.

Hot Lime Process. One standard means of treating boiler makeup feedwater is by the hot precipitation process. This method, while reasonably effective, has certain disadvantages. Significant space is required for equipment, and elaborate chemical feed controls must be maintained to meter lime, soda ash, and, occasionally, phosphates. In addition, soda ash and phosphates are relatively expensive. An ion exchange system solves most problems inherent to the lime processes. In the treatment of water by hot lime/soda followed by phosphate, the most common hot precipitation method, lime and soda ash are first added to the raw water supply. Lime reacts with calcium bicarbonate and soluble magnesium salts in the water, precipitating insoluble calcium carbonate and magnesium hydroxide. The function of soda ash, that is generally added in excess, is to precipitate soluble calcium salts as carbonates from the reaction, as well as carbonates occurring naturally in the water. Generally, hardness is reduced to about 1.5 grains per gallon by addition of approximately 1.5 grains per gallon excess soda ash. However, for many purposes a hardness of 1.5 grains per gallon is objectionable. Consequently, monosodium or disodium phosphate is added in the second stage of treatment. The reaction with phosphate lowers hardness to a few parts per million, but additional carbonate alkalinity is introduced. Thus, steam produced may contain considerably more carbon dioxide than desirable.

Hot Lime and Zeolite Process. Soda ash and phosphates are relatively expensive. To approach zero hardness an excess of phosphate must be present. Unless pH of the water is maintained at about 8.5, there is danger that calcium

phosphate may deposit in second stage heaters or in economizers. Thus, addition of acid is necessary to maintain pH at 8.5. In the hot lime ion exchange process, lime is added to the raw water. Expensive soda ash is not used. As in the hot lime-soda-phosphate method, insoluble calcium carbonate and magnesium hydroxide are precipitated. Hardness is reduced in proportion to the akalinity of the raw water. The effluent, partially softened and of low akalinity, is filtered to prevent fouling of the resin bed with suspended carbonates that may cause decreased capacity and premature breakthrough of hardness. The lime-treated, filtered water is passed through the sodium in the form of a strongly acidic cation exchange resin, which scavenges residual hardness out of the water, yielding makeup water with essentially zero hardness. The amount of phosphate required to complete the job is very small. Since a high-capacity resin is employed, it is able to handle large volumes of water having variable composition, Also, because of this capacity and because influent water from the lime softener is partially softened, the resin only requires regeneration at infrequent intervals. The primary advantages attained with the hot lime and zeolite softener method over the hot lime-soda-phosphate process are as follows:

• Lower cost of lime, salt, and the small quantity of phosphate required, compared to higher costs associated with the hot lime-soda-phosphate method.

• Zero hardness attained.

• Very low carbon dioxide content of steam produced with anion exchange treated water.

• No need for elaborate controls.

• Economy of space achieved.

• Constant quality of effluent despite variations in influent.

Advantages of hot over cold systems are higher rate of lime reaction, lower akalinity and silica, and less corrosion due to near absence of oxygen. Table 4-2 illustrates how each method changes the water. The typical water exhibited contams appreciable permanent hardness, and is especially suited to lime ion exchange treatment. The hot lime-zeolite process is actually very complex to operate and maintain. The unpopularity of this process focuses on high initial cost, complexity of plant, and difficulty of maintaining continuous, trouble-free operation,

TABLE 4-2

Results of Lime Softening

Constituent	PPM as	A	B	C	D
Calcium	$CaCO_3$	200	100	50	Nil
Magnesium	$CaCO_3$	100	90	10	Nil
Sodium	$CaCO_3$	100	100	100*	285*
Total Electrolyte	$CaCO_3$	400	290	285*	285*
Bicarbonate	$CaCO_3$	150	0	0	0
Carbonate	$CaCO_3$	0	40	30	30
Hydroxyl	$CaCO_3$	0	0	5	5
Sulfate	$CaCO_3$	150	150	150*	150*
Chloride	$CaCO_3$	100	100	100*	100*
M alkalinity	$CaCO_3$	150	40	35	35
P alkalinity	$CaCO_3$	0	20	20	20
Carbon Dioxide	$CaCO_3$	5	0	0	0
pH	---	7.5	9.5	10.2	10.2
Silica	SiO_2	10	10	1-2	1-2

Key
A. Typical raw water
B. After cold lime softening
C. After hot lime softening
D. After hot lime/zeolite softening

*These constituents may be reduced as much as 15% due to dilution by condensation of steam used in heating.

   4.2.4 Electrodialysis. In the electrodialysis process (Figure 4-3) water to be treated is passed between pairs of semipermeable membranes that are similar in composition to ion exchange resins. Each membrane allows only one type of ion., cation or anion, to pass through. To move ions through membranes, a direct current is applied to the water from electrodes in compartments outside the membranes. Positive ions are attracted to the negative electrode, and pass through the cation permeable membrane into the concentrated stream compartment. Negative ions pass through the anion permeable membrane into a second concentrated stream compartment. Streams of high mineral concentration are

POSITIVE ELECTRODE **ANION MEMBRANE** **CATION MEMBRANE** **NEGATIVE ELECTRODE**

Ca^+ Na^+ Mg^+

Cl^- SO_4^- HCO_3^-

Ca^+ Na^+ Mg^+

Cl^- SO_4^- HCO_3^-

CONCENTRATED WASTE **DEMINERALIZED WATER** **CONCENTRATED WASTE**
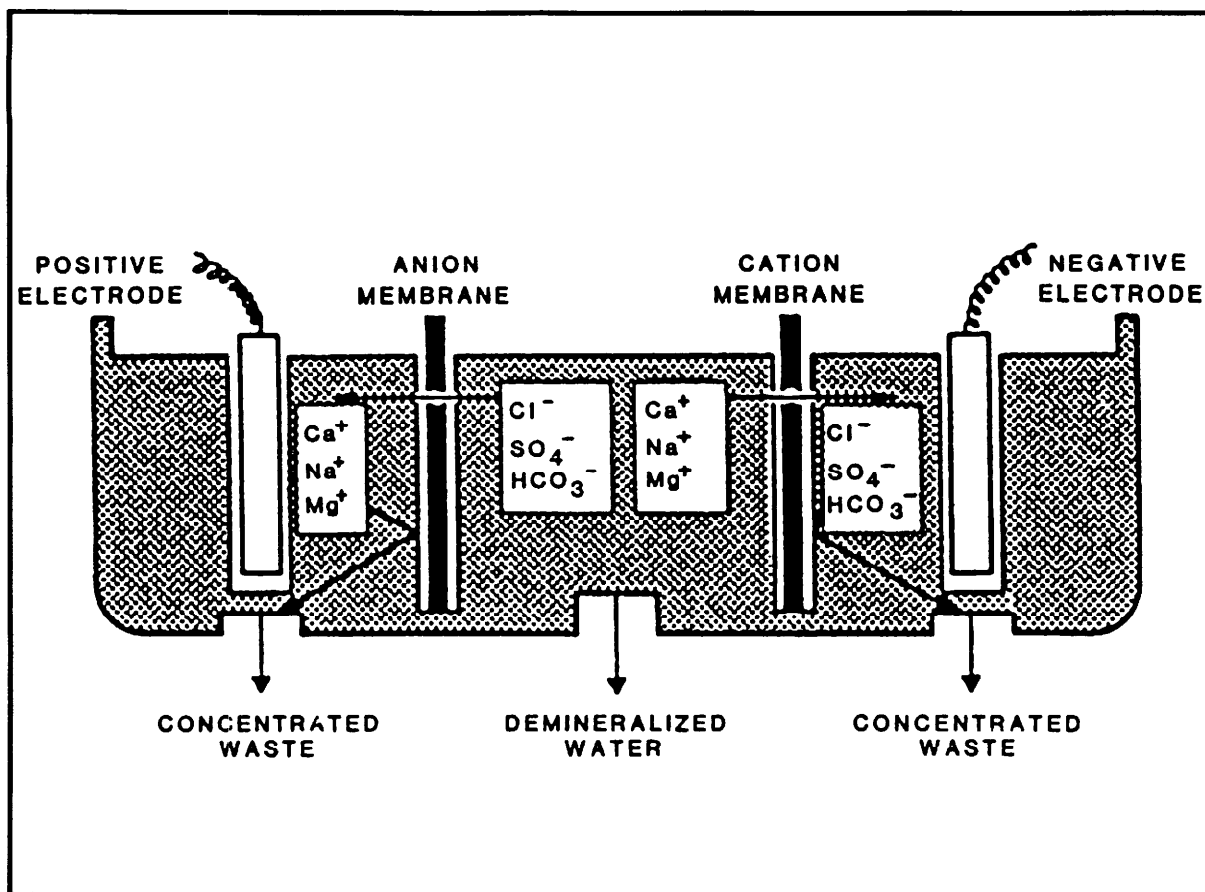
FIGURE 4-3
Electrodialysis Schematic

directed to waste. The purified stream from the center compartment is directed to storage for use. In simple three-compartment cells, efficiency is relatively poor, due to quantities of water wasted and to current-consuming reactions at the electrodes. To improve efficiency, multiple units are used that contain parallel cells with alternating membranes. The electrodialysis process works best if operated continuously; therefore, storage must be available for intermittent demands. Prefiltration of water frequently is desirable because of possible fouling of membranes with organic matter and/or inorganic precipitates. As minerals are removed, electrical resistance of the water and, thus power requirements, are increased. Multiple units in series are required to produce the purest water; but the water will not be as good as that produced by demineralization. Electrodialysis may be either the complete treatment given for noncritical water uses or pretreatment for cost reduction in operating demineralizer equipment. Electrodialysis should be considered where water contains between 500 ppm and 5,000 ppm total dissolved solids (TDS). In the range of 500 to 2,500 ppm, the electrodialysis system uses less energy than a reverse osmosis (RO) system. In the range of 2,500 to 5,000 ppm TDS, electrodialysis may require more power than reverse osmosis.

Operation and Maintenance. Operation and maintenance varies with size of installation, number of stages, feedwater consumption, and product purity required. Labor for manually cleaning stacks can be significant. Replaceable filter cartridges are used for final polishing before feedwater enters the electrodialysis plant. Membrane replacement depends on load factor,.number of stages, and size of plant. Operating labor should average from one-half to one hour per day. Maintenance labor is more difficult to project, but generally 50 to 100 man-hours per stack per year are required, depending on the size of the plant and number of stages. With inadequate prefiltration, major stack cleaning becomes a significant economic factor. Some of the operation and maintenance expenses that should be considered are the costs of:

- Chemicals used to clean stacks.
- Replaceable filter cartridges.
- Membrane replacement.
- Feedwater.
- Wastewater disposal.
- Building.
- Prefiltration and post treatment (if required).

Advantages. Certain advantages are claimed for electrodialysis plants compared to reverse osmosis as follows:

- Neither acid nor other chemicals are required for normal plant operation. This eliminates hazards, inconveniences, and storage problems inherent in acid handling, and minimizes maintenance and corrosion of equipment.
- Electrodialysis plants operate at 30 to 60 psig, compared to a range of 200 to 1,000 psig to drive water through RO membranes.

Low-pressure operation results in lower maintenance requirements and makes fabrication of wetted parts with noncorrosive plastics possible.

- Water from an electrodialysis plant is produced at nearly neutral pH. Conversely, water from an RO plant is normally acidic.
- In virtually all cases, electrodialysis gives the highest treated water yield (lowest blowdown).
- Presoftening is not required for electrodialysis.
- The membrane stack can be cleaned without damage to the system by polarity reversal, by flushing with an acid or a caustic solution, or (in extreme cases) by opening stacks and scrubbing membranes.

The ED stacks are the only membrane modules that can be cleaned in this manner. In contrast, RO membrane modules must be discarded.

4.2.5 Membrane Separation.   Reverse osmosis is a membrane separation process in which the water from a solution is separated from dissolved solids by flowing through an appropriate membrane. Osmosis is a process where water flows from a low concentration solution, through a membrane to a high concentration solution. "Reverse" osmosis overcomes this tendency by pressurizing the high concentration side of the solution and forcing "pure" water to pass through the membrane towards the low concentration side. The differential pressure across the membrane is often greater than 300 psig. The exact pressure differential depends upon both the type of membrane and the concentration of the solids in the feedwater. Reverse osmosis should not be confused with ultrafiltration. Ultrafiltration does not remove solids dissolved in the water. Rather,, this technology only removes suspended materials in the feedwater. Reverse osmosis membranes are rolled into tubes and the surfaces of the tubes are difficult to clean. *Only* the specific chemicals and procedures specified by the reverse osmosis equipment manufacturer should be used for a given model unit. The pre-cleaning, sanitizing or wash cycle chemicals or procedures of a different model reverse osmosis device or equipment manufacturer can readily damage or destroy the sensitive and expensive membrane tubes.

4.2.6 Ion Exchange.   Ion exchange is a flexible method of treating water for boilers and other processes. In this method, more desirable ions are exchanged for less desirable ones. Specific ions removed from solution by the ion exchange process are determined by the type of reactive material (resin) utilized and by the regenerant employed to provide exchangeable ions on the ion exchanger. The regenerant and regeneration process determine the ions that replace those removed from solution during the exchange process and provide the exchange capacity available to the ion exchanger. Almost all dissolved inorganic material found in water is in an ionized state. Undesirable ions can be removed from solution and replaced with an equivalent amount of ions that are acceptable, by selection of the ion exchange process. If all dissolved, ionized material is objectionable, a special exchange process known as demineralization can remove ions and replace them with ions that combine to form water (hydrogen cations and hydroxyl anions) This demineralization process, also known as deionization, can produce water that is essentially free from dissolved ionized impurities. Demineralization is discussed more in detail on page 4-32. There are two fundamental types of ion exchange resins: cation resin, that removes some, or all, cations in the water (calcium, magnesium, and sodium), and anion resin, that removes some, or all, anions in the water carbon dioxide, bicarbonate and carbonate alkalinity chloride, and silica). Several ion exchange

systems are listed in Table 4-3.

TABLE 4-3

Ion Exchange Resin Systems

Cation			Anion		
Weak	Strong	Strong	Weak	Strong	Strong
Hydrogen Zeolite	Hydrogen Zeolite	Sodium Zeolite	Hydroxyl Zeolite	Hydroxyl Zeolite	Chloride Zeolite
Removes Calcium Magnesium (1)	Removes Calcium Magnesium sodium	Removes Calcium Magnesium (2)	Removes Chloride Sulfate (3)	Removes Carbon-dioxide Bicarbonates Carbonate Chloride Sulfate Silica (3)	Removes Bicarbonate Sulfate (4)

Notes: (1) **Hardness associated only with bicarbonate alkalinity.**
         (2) **Water Softener.**
         (3) **Acid forms only.**
         (4) **Dealkalizer.**

Ion Exchange Systems. Ion exchange systems used are water softening and cation exchange. All ion exchangers with single beds of resin are essentially the same and vary only in the type of resin used, the regenerant chemical, and the materials of construction. A typical ion exchanger is shown in Figure 44. The most common form of ion exchange is water softening, where calcium and magnesium ions are exchanged for sodium ions. In the second system, a strong acid cation exchanger in the hydrogen cycle replaces all cations with hydrogen ions. The acidic water then passes through a strong base anion exchanger in the hydroxyl caustic) cycle that replaces all anions, including silica, with hydroxyl ions.

Most ion exchangers are relatively complex systems that may experience malfunction. In troubleshooting ion exchanger malfunctions, accurate records of
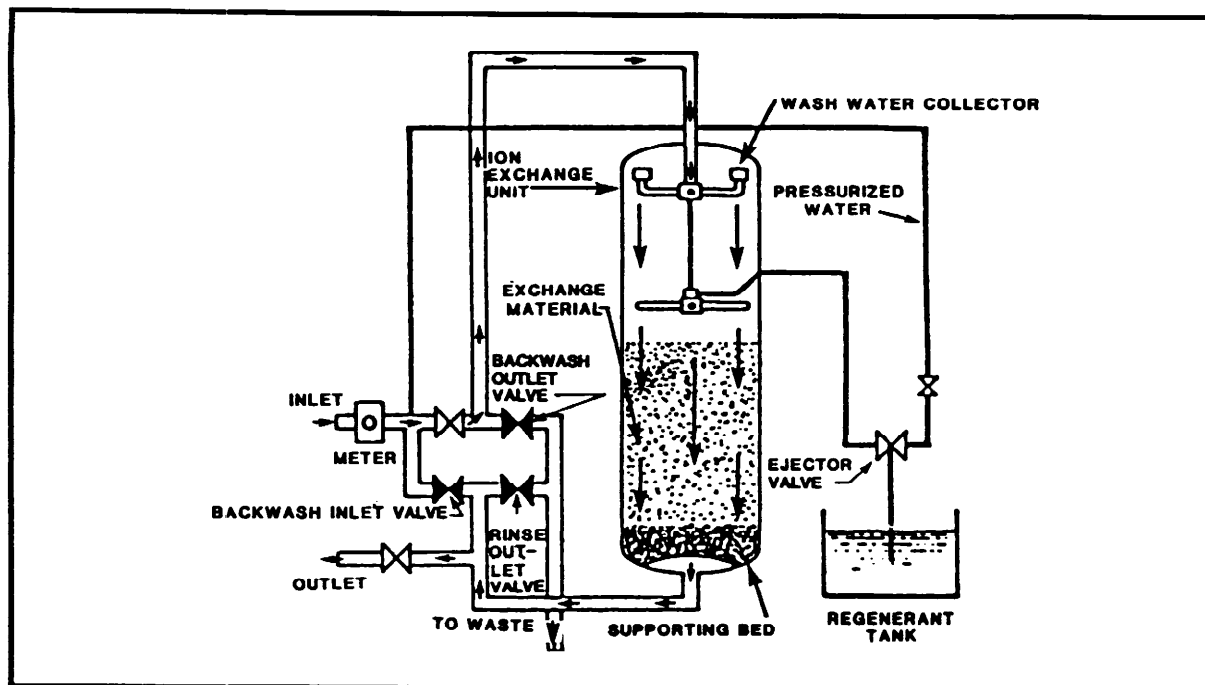
FIGURE 4-4
Typical Ion Exchanger
(Courtesy Drew Chemical Company)

OPERATION

SERVICE: Water to be treated passes downward through the bed of ion ex-
change resin until its capacity for exchange is exhausted. Once exhausted, it can
be regenerated.

BACKWASH: the flow of water is reversed and moves upward through the
resin this process removes accumulated suspended matter (resin is a good fil-
ter medium) and resin
fines (broken resin beads). It also frees or fluffs the resin to ensure good dis-
tribution.

REGENERANT INTRODUCTION: Diluted chemical (salt, acid, or caustic)
is introduced downward through the resin, removing exchanged ions, that are
subsequently discharged.
This restores exchange capacity.

DISPLACEMENT: Water flows downward through the resin at a low flow rate,
displacing the regenerant chemical (piston action). This process is often called
slow rinse.

RINSE: A rapid downward flow of water removes all traces of regenerant
chemical.

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plant operation are important. Records should include the following information:

- Flows: Volume treated, normal flow rate, peak flow rate.
- Pressure: Supply and treated water differential between units, on multiple bed units; readings should be correlated with temperature and flowrate.
- Resin: Type, bed depth, installation date, analysis results.
- Regeneration: Frequency, amount of concentrated chemical, time of introduction, concentration at resin, rate of flow of concentrated chemical and dilution water, source of dilution water, wash flow and duration, slow rinse flow and duration, fast rinse flow and duration.
- Water: Analysis of raw water, treated water, and water between units on multiple bed units.
- Design Criteria: Operating conditions for the system compared to original design criteria.

Softening and Dealkalization. Many waters should be softened and dealkalized before they are suitable for use, and several successful ion exchange processes have been developed to fulfill this need. The most prominent of these are: sodium zeolite/hydrogen zeolite splitstream softening; sodium zeolite/chloride anion dealkalization; weakly acidic cation exchange.

Sodium Zeolite/Hydrogen Zeolite Splitstream Softening. The sodium zeolite/hydrogen zeolite splitstream softening system consists of one or more brine regenerated sodium zeolite softeners and one or more hydrogen zeolite softeners containing a strongly acidic cation exchange resin that is regenerated with acid. Water passes through the sodium zeolite and hydrogen zeolite units in parallel, and then their effluents are blended to produce water of a desired alkalinity. During a typical hydrogen zeolite service cycle, free mineral acids are produced throughout the service run with only minor variations prior to exhaustion. Treated water is almost completely free of calcium and magnesium ions. The amount of sodium leakage depends primarily on the ratio of sodium to total cations, the ratio of alkalinity to total anions in the raw water, and the resin regenerant dosage. In general, leakage increases as raw water sodium concentration increases, and decreases as raw water alkalinity and resin regenerant levels increase. The concentration of free mineral acidity drops sharply as a hydrogen zeolite column nears exhaustion. At this point, the resin must be regenerated by treating it with an acid solution. Although other acids can be used, sulfuric acid is usually preferred for economic reasons. The high acid concentration provides the driving force for displacing calcium, magnesium, and

sodium ions with hydrogen ions. As with the sodium zeolite softener, an excess of regenerant must be used. Water produced by sodium and hydrogen zeolite columns is extremely soft (low in calcium and magnesium). Sodium zeolite water contains a mixture of sodium salts, and hydrogen zeolite water contains a mixture of acids. Sodium zeolite alkalinity (sodium bicarbonate) is used to neutralize the mineral acids. In addition to neutralizing mineral acids, these processes convert sodium alkalinity to carbonic acid that is very unstable in aqueous solutions, and is, therefore, easily removed by degasification in a forced draft or vacuum degasifier. Alkalinity of treated water is maintained at the desired level by varying percentages of sodium and hydrogen zeolite water in the blend. For a given water, the higher the sodium zeolite percentage, the greater the alkalinity; the higher the hydrogen zeolite percentage, the lower the alkalinity.

System Design. The hydrogen zeolite/sodium zeolite splitstream softening system consists of one or more hydrogen zeolite columns, one or more sodium zeolite columns, a deaerator or degasifier, and a blending control system. Figure 4-5 is a flow diagram for a typical system.

4-20
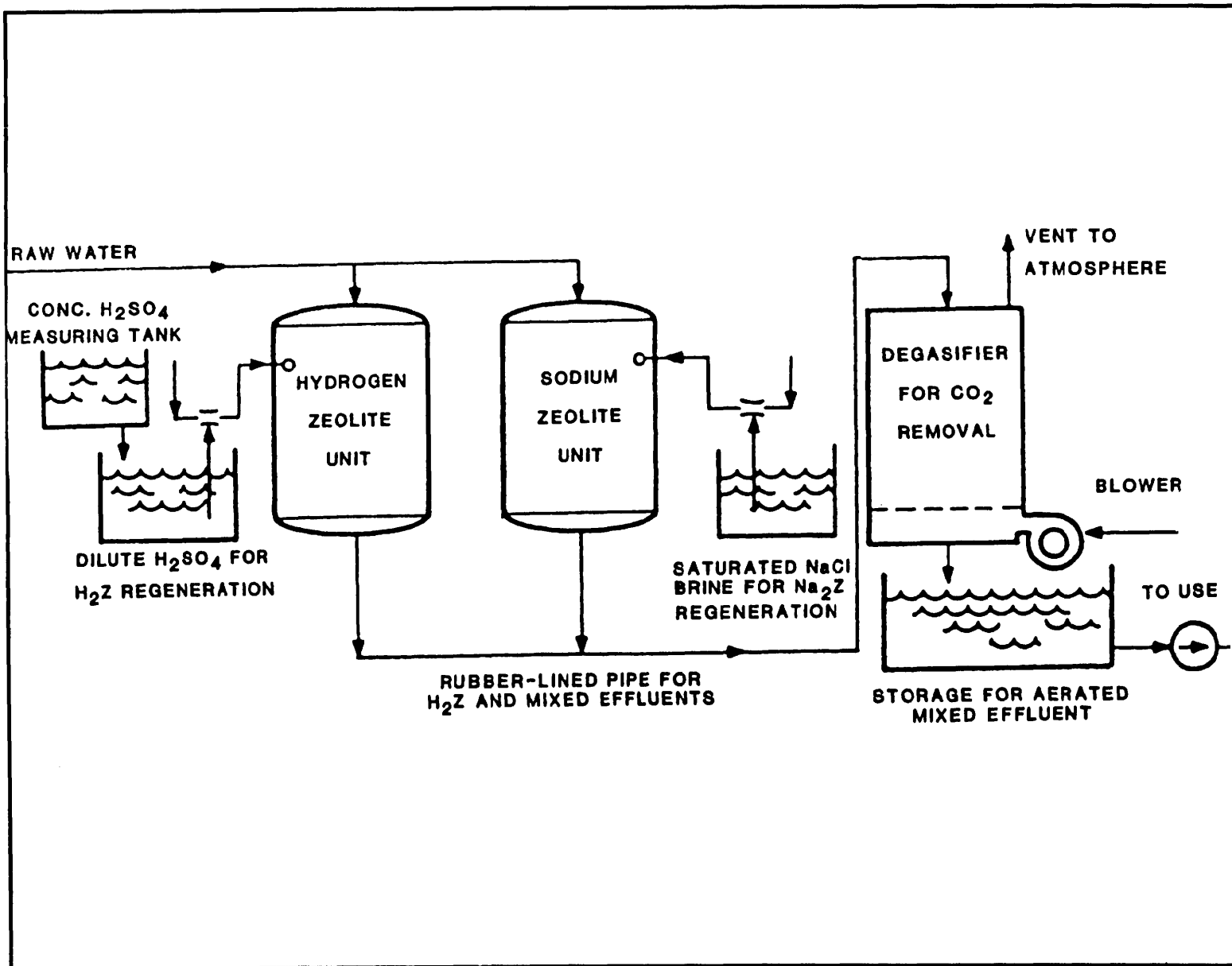
FIGURE 4-5
Hydrogen and Sodium Zeolite Units in Parallel
(Courtesy Betz)

RAW WATER

CONC. H_2SO_4
MEASURING TANK

DILUTE H_2SO_4 FOR
H_2Z REGENERATION

HYDROGEN
ZEOLITE
UNIT

SODIUM
ZEOLITE
UNIT

SATURATED NaCl
BRINE FOR Na_2Z
REGENERATION

RUBBER-LINED PIPE FOR
H_2Z AND MIXED EFFLUENTS

VENT TO
ATMOSPHERE

DEGASIFIER
FOR CO_2
REMOVAL

BLOWER

TO USE

STORAGE FOR AERATED
MIXED EFFLUENT

The primary difference between hydrogen and sodium systems is the hydrogen zeolite system uses materials suitable for acid service. The regenerant system is designed to handle sulfuric acid. A number of arrangements are provided for preparing the 2 to 6 percent acid concentration needed for regeneration. The most effective, and by far the safest, uses in-line blending of concentrated sulfuric acid with dilution water that flows at a constant rate. Concentrated sulfuric acid enters the dilution line through a suitable mixing tee where flow of concentrated acid is regulated to provide the desired regenerant concentration. Blending control, that proportions the sodium to hydrogen zeolite flow, is usually a simple rate-of-flow controller, but automatic analyzers can be used to compensate for changes in raw water characteristics and to ensure better control of alkalinity. Degasifiers for removing carbon dioxide usually consist of wood towers or packed columns with forced draft fans. Blended effluent from ion exchange columns is distributed over the top of the degasifier. Wood slats or packing break the water into fine droplets or films. Air introduced at the bottom of the degasifier flows countercurrent to the falling water and scrubs carbon dioxide from the effluent. Occasionally, vacuum degasifiers are used to remove carbon dioxide. A rubber-lined, steel column is filled with packing to break the water into fine droplets and films, and steam jet ejectors that apply a vacuum to the column strip dissolved gases from the water. Operation of hydrogen zeolite and solium zeolite softeners is similar. Both use the same basic service and regeneration cycles. Service water and regenerant flows follow identical paths with the same flow rate restrictions. The only major differences are methods for determining the end of the service cycle and the use of sulfuric acid as the regenerant in hydrogen zeolite softening rather than salt brine.

Sodium Zeolite/Chloride Anion Dealkalization. Sodium zeolite/chloride anion dealkalization systems have one, or more, sodium zeolite softeners and one or more chloride anion dealkalizers. Water should first flow through the softener and then through the dealkalizer where bicarbonate, sulfate, and nitrate anions are replaced. with chloride anions in the softened water. Figure 4-6 shows equipment arranged in series, from the sodium zeolite softener to the dealkalizer. Construction of the dealkalizer is nearly identical to the sodium zeolite softener. The major differences are the use of a strongly basic anion exchange resin in the dealkalizer and provision for addition of small amounts of caustic soda with the salt brine during regeneration. The chloride anion dealkalizer differs from the sodium zeolite softener only in specific controls used. The service water and regenerant flows follow the same routes through the equipment.

Weak Acid Cation Exchange. Another approach to softening and dealkalization uses weakly acidic (carboxylic) cation exchange resins. Water passes through a column containing this resin in the hydrogen form, and calcium, magnesium, and sodium ions associated with alkalinity are exchanged for hydrogen ions. Raw water characteristics determine final treated water quality. Because raw
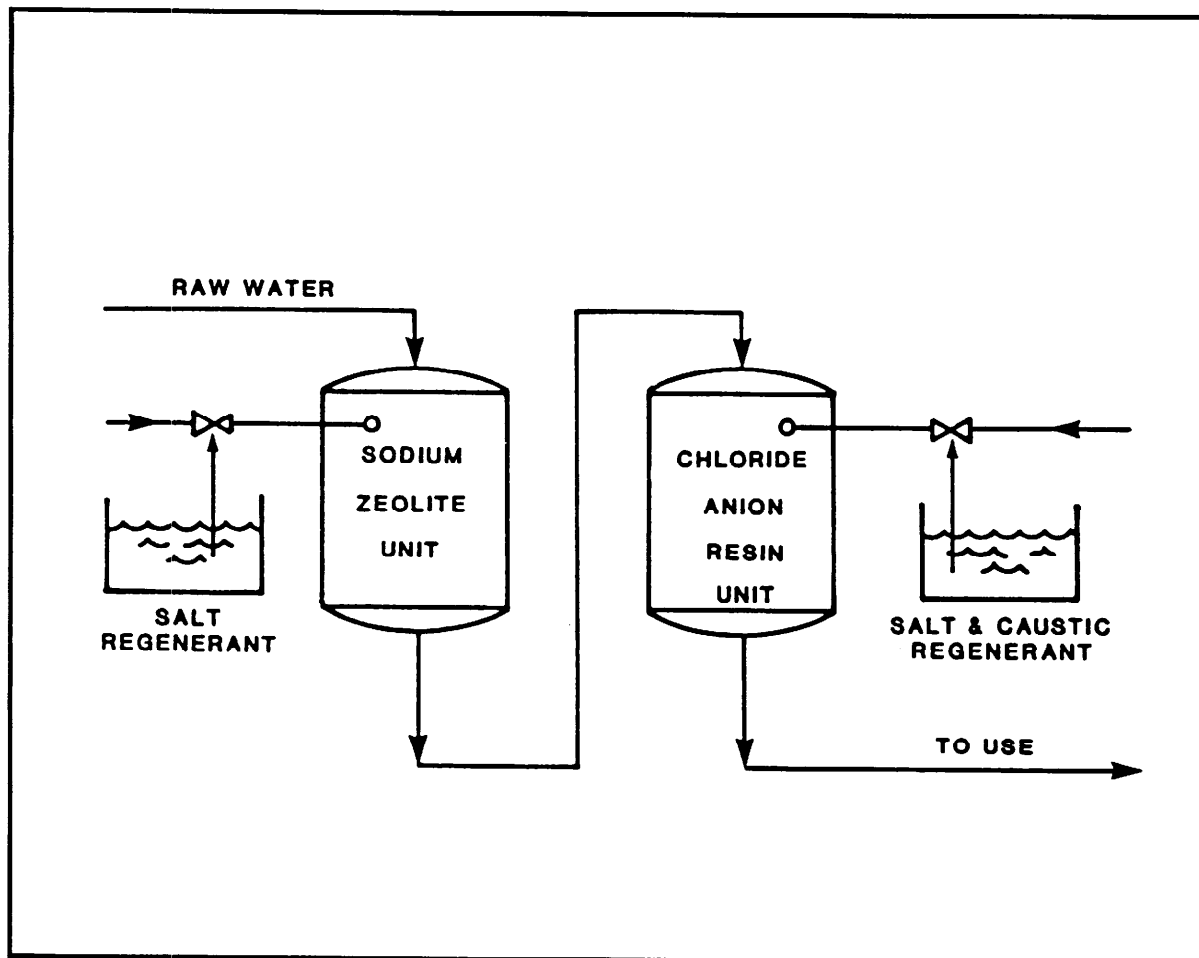
FIGURE 4-6

Sodium Zeolite/Chloride Anion Exchanger
(Courtesy Betz)

water cations associated with sulfate, chloride, and nitrate anions usually pass unaffected through the weakly acidic resin column, treated water will contain hardness, if the raw water hardness exceeds the alkalinity. For example, raw water hardness and alkalinity levels of 150 and 100 ppm, respectively, produce a treated water hardness level of nearly 50 ppm. Consequently, the weakly acidic resin column may need to be followed by a sodium zeolite softener to remove remaining hardness. Regeneration frequency of a weak acid cation exchange resin column is usually determined by treated water hardness or alkalinity level. Regeneration is accomplished by treating the resin bed with a sulfuric acid solution Since regeneration efficiency of these resins approaches 90 percent, only slightly more than the theoretical quantity of acid is required to regenerate columns. The weak acid cation exchange unit is identical to the standard hydrogen zeolite unit. The difference in performance is a result of using weakly

acidic resin. The weakly acidic resin unit is followed by a sodium zeolite softener and a degasifier. Another arrangement provides a layer of strongly acidic cation resin beneath weakly acidic resin, rather than a separate sodium zeolite softener. Provisions for applying a salt wash after acid injection may be included. Operation of a weak acid cation exchanger and sodium zeolite and hydrogen zeolite softeners are similar, differing only in specific controls used. Sulfuric acid is normally used for regeneration, but because weakly acidic resin displays a great affinity for calcium, the resin is more susceptible to calcium sulfate precipitation than strongly acidic resins used in the typical hydrogen zeolite unit. To avoid precipitating calcium sulfate, closely follow equipment manufacturer's instructions.

Applications and Advantages. The sodium zeolite/hydrogen zeolite splitstream process produces low hardness, low alkalinity water, and reduces the dissolved solids content in direct proportion to alkalinity reduction. The process is suitable for producing boiler feedwater for small-to medium-sized systems. The sodium zeolite/chloride anion dealkalizer system produces water low in hardness and low to moderate in alkalinity. Alkalinity is reduced without the hazard of handling acid and, although caustic soda used with the salt regenerant improves the operating capacity, salt alone is adequate. This process is used primarily to produce boiler feedwater for small plants. Weak acid cation exchange produces water of quality comparable to that of the sodium zeolite/hydrogen zeolite splitstream system. Excellent hardness and alkalinity reduction can be achieved with a corresponding reduction in dissolved solids content. Because weakly acidic resin has a high regeneration efficiency, it offers a substantial economic advantage. This system can usually be installed wherever sodium zeolite/hydrogen zeolite splitstream softening systems have been used, but system selection must be based on specific plant needs.

Limitations. Softening and dealkalizing processes, like other ion exchange systems, function efficiently only if the raw water is free from suspended matter. Iron and aluminum in the raw water supply can foul sodium zeolite softeners and, under certain circumstances, can also foul acid regenerated ion exchangers. Chlorine, or other oxidizing agents, in the water supply attack ion exchange resins and significantly reduce their useful life. Softening and dealkalization processes do not reduce raw water silica content. Splitstream and weak acid cation exchange systems decrease dissolved solids to a limited extent, but chloride anion dealkalization does not significantly affect dissolved solids. Water produced by systems using forced draft degasifiers becomes saturated with oxygen and is highly corrosive.

Ion Exchange Troubleshooting. Table 4-4 is a troubleshooting guide for ion exchanger problems compiled by the Drew Chemical Corporation.

TABLE 4-4

Ion Exchanger Troubleshooting Guide

PROBLEM	PROBABLE CAUSE	CORRECTIVE ACTION
High Pressure Drop	Valve partially closed	Check and adjust all valves.
	Internal distributor blockage with resin, iron, debris	Backwash Inspect Repair/clean distributors
	Increased flow rate	P increases with flow
	Increased SS loading influent	Mid cycle backwash
	Bed compaction	Air or mechanical stir to supplement backwash
	Resin fines	Remove with backwash
	Cation resin decross-link	Analyze resin Replace if 60% or higher moisture
	Lower water temperature	P increases with higher viscosity at low temperature
	Broken underdrain, resin or subfill in collectors or outlet pipe	Inspect internals
	Channeling	Backwash Check collectors Check valve operating speeds Check for support bed upset
	Poor backwashing	Regular check of flow and duration Adjust with changes in water temperature and pressure
	Anion resin bed depth increase in multibed	Underdrain failure Resin passing to unit which follows

TABLE 4-4

Ion Exchanger Troubleshooting Guide (continued)

PROBLEM	PROBABLE CAUSE	CORRECTIVE ACTION
High Pressure Drop (con't)	Biological growths	Chemically clean Pretreat to control organisms
Low Pressure Drop	Reduced flow	P decreases with flow
	Increased temperature	Lower viscosity Check wash rate at higher temperature
	Resin loss, reduced bed depth	Check for loss to sewer during wash Underdrain failure Resin decross-link reduces density Resin attrition due to age Oil contamination Flotation due to released gases if wash inlet valve used to throttle
Softener Poor Quality	All of the items listed below for loss of Capacity can also be checked regarding poor quality Valve leakage	Check bed sample vs outlet pipe sample (before and after valving) Special caution on wash inlet valve Check limit stops on electric valves Check air pressure on pneumatic valves Check fluid pressure on hydraulic Check sealing gaskets on multiports Check for physical damage due to water hammer if problem appears on all units at same time Check supply header (air or fluid) size and pressure
	Excessive flow rates	Insufficient reaction time Reduce flow

TABLE 4-4

Ion Exchanger Troubleshooting Guide (continued)

PROBLEM	PROBABLE CAUSE	CORRECTIVE ACTION
Softener Poor Quality (con't)	Low flow rates	Poor distribution channeling Place one or more units in standby Recycle treated water to inlet
	Low temperature	Slow reaction rates Reduce flow rates Preheat feed
	Iron in treated water	Resin fouled Chemically clean Pretreat for removal prior to exchanger Additivies during each regeneration
Softener Loss of Capacity	Increased loading and/or distribution of exchangeable ions	Increase regenerant Add resin Investigate pretreatment
	Over run capacity, previous run	Normal regenerant does not restore Double regenerant Adjust end of run determination
	Iron, manganese, aluminum coating and precipitates	Check water supply Check wash Check regenerant chemicals for contaminants Chemically clean resins Pretreat for removal
	Channeling, poor distribution	Check wash SS loading Iron and other metals Low flow Poor distribution Broken or clogged distributors

TABLE 4-4

Ion Exchanger Troubleshooting Guide (continued)

PROBLEM	PROBABLE CAUSE	CORRECTIVE ACTION
Softener Loss of Capacity (con't)	Resin age	Up to 5%/yr. loss in capacity considered normal Check resin moisture to show decross-link Analyze resin to determine remaining useful life
	Resin loss	Excessive waste wash overdrain failure Decross-link Flotation by dissolved gas (inlet) throttle
	Regenerant concentration and quantity	Check pumps, ejectors, drawdown, etc Check dilution flows, time settings Apply correct amount at correct concentrations
	Excessive rinsing	Analyze for end of rinse determination. Adjust rinse period to suit
	Resin oxidation	Presence of oxidants (chlorine) and oxygen in presence of catalysts (iron) decross-linking which reduces capacity and eventually high pressure drop. Replace if 60% moisture or higher
Hydrogen Cation Loss of Capacity	All of the items listed for loss of capacity softeners can be checked for a hydrogen cation exchanger	
	Calcium sulfate precipitation (barium sulfate precipitation)	Sulfuric acid regenerant units Calcium in treated water Remove with chemical cleaning Readjust acid concentration

TABLE 4-4

Ion Exchanger Troubleshooting Guide (continued)

PROBLEM	PROBABLE CAUSE	CORRECTIVE ACTION
Hydrogen Cation Loss of Capacity (con't)	Calcium phosphate, colloidal silica, zirconium, titanium oxides, oils, grease	Chemically clean Pretreatment for removal before exchanger
Hydrogen Cation Poor Quality	All of the items listed for poor quality softeners can be checked for a hydrogen cation exchanger	
	Calcium in treated water (should be zero)	Calcium sulfate precipitation on sulfuric acid regenerants Clean Adjust acid concentration and time of application Calcium phosphate or other complete you feed
	Hardness in treated water (should be zero)	Valve leakage High flow Channeling Poor distribution
	Excess sodium in treated water	Overrun capacity Check regenerant concentration and quantity Investigate upflow or hydrochloric acid Regenerate
Weak Base Anion Loss of Capacity	Increased loading of exchangeable ions	Add resin Increase regenerant if applicable to resin being used

TABLE 4-4

Ion Exchanger Troubleshooting Guide (continued)

PROBLEM	PROBABLE CAUSE	CORRECTIVE ACTION
Weak Base Anion Loss of Capacity (con't)	Excessive Rinsing	Oxidation of resin to weak acid Retains sodium Replace resin Use ammonia as regenerant Recycle rinse water Analyze for end of rinse determination Adjust rinse period to suit
	Silica precipitation	On series regenerant Strong/weak base Chemically clean Dump first portion of strong base regenerant
	Resin age	Up to 20%/year loss in capacity considered normal Analyze resin to determine remaining useful life
	Chemical precipitation	Hardness in regenerant dilution and/or rinse waters Precipitated calcium carbonate and magnesium hydroxide Use soft, decationized or demineralized water Check cation unit
	Resin loss	Resin is light, easily lost, subject to flotation by released gases Adjust wash rate to suit temperature and/or pressure changes
	Channeling, poor distribution, regenerant concentration & quantity	As discussed previously

TABLE 4-4

Ion Exchanger Troubleshooting Guide (continued)

PROBLEM	PROBABLE CAUSE	CORRECTIVE ACTION
Weak Base Anion Poor Quality	Chloride in treated water	Check cation performance Chloride equal to sodium leakage normal Check regenerant for high chloride content Check for leaking regenerant (caustic) valve Check for silica precipitation on series strong/weak systems
	Treated water high pH	Check for leaking regenerant valve
	Hardness in treated water	Check cation performance Check for hardness in all waters used for regeneration to eliminate precipitates
	Excessive sodium in treated water	Not enough rinse Resin oxidation Analyze resin Check for presence of cation resin
	Leakage of all exchangeable ions	Leaking valves Excessively high or low flows Channeling Poor distribution Total exhaustion
	Fouling	Organics and others Chemically clean Pretreat for removal Replace with more suitable resin
	Overrunning	Reduce throughput Evaluate end of run determination

TABLE 4-4

Ion Exchanger Troubleshooting Guide (continued)

PROBLEM	PROBABLE CAUSE	CORRECTIVE ACTION
Strong Base Anion Loss of Capacity	Increased loading of exchangeable ions	Add resin Increase regenerant Check degasifier (if present) for carbon dioxide removal Check for change in % anions
	Excessive rinsing	Analyze for end-of-rinse determination Adjust rinse period to suit Recycle rinse water
	Chemical precipitation	Hardness in regenerant water and/or leakage from cation unit
	Heavy metal fouling	Check cation for fouling Check regenerant for iron Chemically clean
	Organic Foiling	Pretreat for removal Chemically clean resin Oxidation of cation resin can foul anion
	Resin age, resin loss, channeling, poor distribution regenerant concentration, quantity, over-exhaust ion	As in weak base and previous notes (excessive caustic concentration reduces capacity)
	Excessive microbiological growths	Chemically clean Pretreat to control organisms

Demineralization. Demineralization, applied to water treatment, is removal of essentially all inorganic salts by ion exchange. In this process, hydrogen cation exchange converts dissolved salts to their corresponding acids, and basic anion exchange removes the acids. The only other commercial process that produces water of comparable purity is distillation. Because demineralization of most freshwater supplies is substantially less expensive than distillation (evaporation), it is widely used. A demineralizer system consists of one, or more, ion exchange resin columns containing strongly acidic cation and anion exchange resins. The cation resin exchanges hydrogen for cations in raw water and the anion resin exchanges hydroxyl anions for the highly ionized anions. If the anion exchange resin is strongly basic, it will also remove such weakly ionized compounds as carbonic and silicic acids. If the anion resin is weakly basic, it will not remove weakly ionized compounds. Because exchanges are not 100 percent efficient, some mineral ions remain in the treated water. The presence of these ions is known as leakage. The amount of mineral contamination leakage in the demineralized water varies according to the demineralizer system used and the raw water mineral composition and demineralizer regenerant level (the amount of acid and caustic used for regeneration). Demineralizers that are employed where silica removal is not critical use weak base anion resins and specific conductance becomes the primary parameter for evaluating water quality. Such demineralizers use strong base anion resins where both silica content and specific conductance are important water quality criteria. Both values are high after regeneration and low after rinsing to produce satisfactory water quality. The silica level, nearly constant during the entire service run, increases sharply at the end. Conductivity, also nearly constant during the service run, drops briefly at the end and then rises. Demineralization systems for producing water of extremely high purity use mixed bed demineralizers (a mixture of strongly acidic cation and strongly basic anion resins in the same column). The quality of treated water decreases when resin capacity is exceeded. This indicates a need to regenerate the unit. The cation exchange resin is regenerated with acid as descrilbed for the hydrogen zeolite unit. The anion exchange resin is regenerated with an alkaline material. Caustic soda is the most common regenerant.

Equipment. The demineralization system varies according to requirements of the application. Table 4-5 shows nine basic demineralizer systems and lists areas of application, typical treated water quality, and relative advantages and disadvantages of each. Cation and anion exchange columns used for demineralization are similar to those described for hydrogen zeolite softening. The only difference is the use of anion resin in the anion exchange column. Piping,, valves, and fittings are of either lined or acid-resistant materials. Where

TABLE 4-5

Demineralizer Systems
(Courtesy Betz)

DEMINERALIZER SYSTEM	APPLICATION	TYPICAL EFFLUENT	ADVANTAGES AND DISADVANTAGES
SA → WB	Silica and CO_2 are not objectionable.	Specific conductance 10-30 micromhos. Silica unchanged.	Low equipment and regenerant costs.
SA → WB → D	Silica is not objectionable but CO_2 removal is required.	Specific conductance 10-20 micromhos. Silica unchanged.	Low regenerant costs, but requires repumping.
SA → SB	Low alkalinity raw water, silica removal required.	Specific conductance 5-15 micromhos. Silica 0.02 to 0.10 ppm.	Low equipment costs, repumping not required, high chemical costs.
SA → D → SB	High alkalinity, raw water, silica removal required.	Specific conductance 5-15 micromhos. Silica 0.02 to 0.10 ppm.	Low chemical costs, repumping is required.
SA → WB → D → SB	High alkalinity, sulfate and chloride raw water, Silica removal required.	Specific conductance 5-15 micromhos. Silica 0.02 to 0.10 ppm.	Low chemical costs, high equipment costs, repumping required.
WA → SA → D → WB → SB	High hardness, alkalinity, sulfate and chloride raw water. Silica removal required.	Specific conductance 5-15 micromhos. Silica 0.02 to 0.10 ppm.	Lowest chemical cost, high equipment cost, repumping required.
SA → D → SB → SA → SB	High alkalinity, high sodium raw water, high purity treated water required.	Specific conductance 1-5 micromhos. Silica 0.01 to 0.05 ppm.	Low chemical costs, high equipment costs, repumping required.
MB	Low solids, raw water, high purity treated water required.	Specific conductance is less than 1 micromho. Silica 0.01 to 0.05 ppm.	Low equipment cost, high chemical cost.
SA → D → SB → MB	High alkalinity and dissolved solids raw water, high purity treated water required.	Specific conductance is less than 1 micromho. Silica 0.01 to 0.05 ppm.	Lower chemical cost, higher equipment cost, requires repumping.

KEY

SA STRONGLY ACIDIC HYDROGEN CATION	WA WEAKLY ACIDIC HYDROGEN CATION	WB WEAK BASE ANION	SB STRONG BASE ANION	D DEGASIFIER OR VACUUM DEAERATOR	MB MIXED BED

required, either the deaerator or the vacuum degasifier is identical in design to the unit used in splitstream softening. The mixed bed demineralizer is similar to the hydrogen zeolite softener, except that the resin bed is a mixture of cation and anion exchange resins.

Demineralizer Operation. Demineralizers operate like other ion exchange systems. Cation exchange resin columns operate in the same manner as hydrogen zeolite softeners. Anion exchange resin columns follow the same basic service and regeneration cycles. The only differences are use of an alkaline regenerant and specific controls. When ultra-pure water is required, such as in shore-to-ship feedwater, the mixed bed demineralizer is used. The mixed bed represents an infinite Series of cation-anion exchange systems through a uniform mixture of hydrogen cycle strong-acid cation and hydroxyl cycle strong-base anion resins. A mixed bed demineralizer operates similarly to other ion exchange systems. Effluent silica content and conductivity remain at low, constant levels until the end of the service run; then, both values increase. Conductivity measurements determine the point where regeneration is required. Resins should be separated in a mixed bed demineralizer system before regeneration can start. Resins in a mixed bed unit are regenerated in the operating column. Normal backwashing separates resins by causing the less dense anion exchange resin to rise to the top. When the resin has settled after backwashing, a distinct line, visible in the sight glass, marks separation of cation and anion resin layers. If the two resins do not separate during the backwash cycle, backwashing should be continued until distinct separation is clearly visible. Once the resins have been separated, they can be regenerated by acid and caustic treatment. Acid introduced through the bottom distributor, flows upward through the cation resin and out through the interface collector to waste. Caustic is added through the upper regenerant distributor that is located just above the resin bed, and flows downward through the anion resin and out through the interface collector to drain. Depending on design, acid and caustic can be added as separate regeneration steps of added simultaneously. After acid and caustic treatments, the unit is given a short rinse, drained, and thoroughly mixed by air injected from the bottom distributor. The unit is then refilled with water and rinsed to waste until effluent is of acceptable quality. Mixed bed demineralizers can be designed for regeneration external to the demineralizer service shell. Resins are sluiced to regeneration facilities, separated by backwashing, and regenerated in a normal manner. This method provides nearly continuous service from one unit, Since a spare charge of freshly, regenerated resin can be available for replacement. This method reduces the chance of inadvertently contaminating treated water with either acid or caustic regenerants. Because of the complexity of regeneration in a mixed bed system, the following areas are to be monitored closely:

- Frequency of Process.
- Time of Introduction.

- Chemical Rate of Flow.
- Dilution Water Source.
- Slow Rinse Flow.
- Fast Rinse Flow.
- Amount of Concentrated Chemical.
- Concentration of Resin.
- Dilution Water Rate of Flow.
- Wash Flow and Duration.
- Slow Rinse Duration.
- Fast Rinse Duration.

Other Processes. Recent developments in ion exchange have led to new techniques of problem solving and to more economical demineralization approaches. One relatively new development is commercial application of continuous, countercurrent ion exchange that uses ion exchange resins more efficiently than traditional fixed bed systems. This process passes water through the resin column so that it first penetrates nearly exhausted resin and progressively reaches resin in higher stages of regeneration until, just before leaving the column, it passes through freshly regenerated resin. Exhausted resin is frequently removed from the service vessel and regenerated in separate units before being returned to the main vessel. Another significant development uses layered resin beds, with weakly basic and strongly basic anion resins in the same column. Because weakly basic resin is less dense than strongly basic resin, backwashing after regeneration causes weak base resin to form a layer on top of strong base resin. If weak base resin is selected properly, the layer it forms will protect the strong base resin from organic fouling and will also remove mineral acidity economically. This technique can be applied to cation units where weakly acidic (carboxylic) cation resin is used in the same vessel as strongly acidic cation resin. In both cases, significant regenerant savings can result.

Applications and Advantages. Demineralization produces high purity water for nearly every use. Demineralized water is widely used for high-pressure boiler feedwater, chemical process water, electronics production, pharmaceutical manufacturing, and research applications. Demineralization systems produce water of a purity comparable to that from distillation, usually at a fraction of the cost. Demineralization systems are available in a wide range of sizes, from small laboratory columns, rated for a few gallons per hour, to large units that produce thousands of gallons per minute. Efficient operation can be achieved in almost any size system.

Limitations. Like other ion exchange systems, demineralizers function efficiently only if the water supply is free from suspended matter and oxidizing materials such as chlorine. Anion exchange resins are more susceptible to oxidants than cation resins. Thus, removal of oxidants is necessary for good demineralizer performance. Standard demineralizer resins cannot remove colloidal or some organically-sequestered materials, and their unexpected presence can cause silica or iron contamination in demineralized water supplies. While some organic materials will pass through demineralizer columns, others may seriously foul anion resin beds.

CHAPTER 5. WATER QUALITY AND TREATMENT REQUIREMENTS

5.1 HEATING AND POWER PLANTS.

5.1.1 Introduction. The necessity for high quality feedwater in industrial use is predicated on preservation of equipment, reduction in maintenance, and efficiency of plants and systems. The areas of greatest concern that use feedwater are heating and power plants, including steam and water supplied to ships, cooling water systems for power and refrigeration plants, air compressors, heat exchangers, and engines with open surge tank systems. Associated with processes to produce high quality feedwater is the safety required in handling and use of chemicals. Quality feedwater production involves the following:

- System components.
- Pretreatment/Objectives.
- System problems.
- Deposits/Control.
- Deposit problems.
- Corrosion/Prevention.
- High temperature water.
- Pretreatment.
- Open/Closed systems.
- Fouling.
- Wood deterioration.

Specific water treatment programs for a variety of alternative boiler, cooling tower, closed loop heating and cooling, and high temperature hot water systems are included as an appendix to this manual. While these programs are not all encompassing in the types of mechanical systems and water sources at military installations, they are representative of many typical system configurations.

5.2 SYSTEM COMPONENTS.
Before considering boiler water treatment, it is helpful to focus briefly on the important functional components of a typical steam generation system. Figure 5-l on page 5-2 illustrates a typical high pressure system (600 psig and greater).

5.2.1 Pretreatment Processes. Variables that should be considered before selection of a pretreatment process are as follows:

LEGEND:

BFP – BOILER FEED PUMP
C   – CONDENSATE
CBD – CONTINUOUS BLOWDOWN
CW   – COOLING WATER
FS   – FLASHED STEAM
LPFS – LOW-PRESSURE FLASHED STEAM
RS   – REDUCED STEAM
ST   – STEAM
#1   – HIGH PRESSURE
#2   – LOW PRESSURE

Figure 5-1
Steam Generating System for Power Generation and Heating
(Courtesy Drew Chemical Company)

5-2
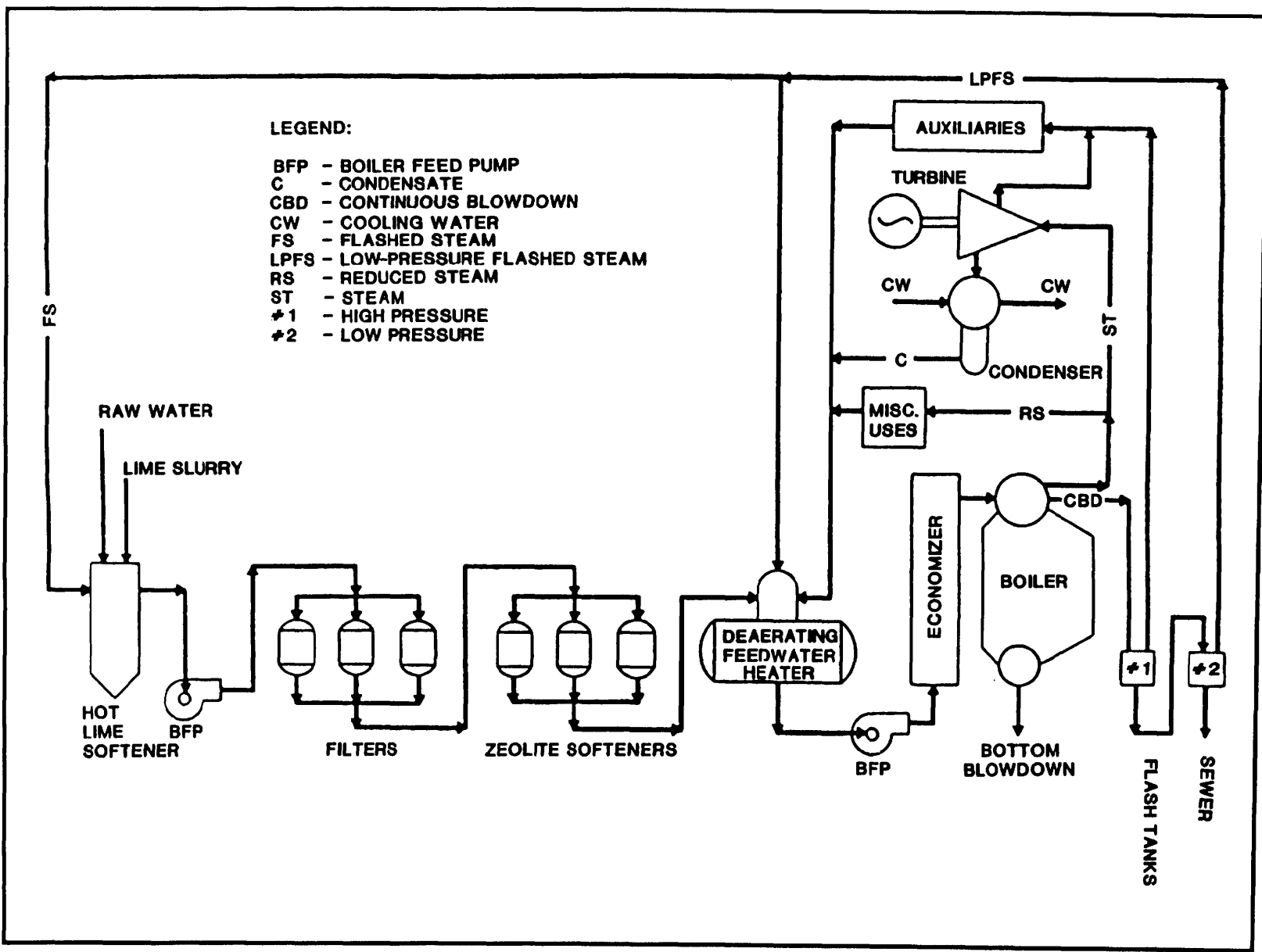
- Raw water characteristics.
- Type of boiler.
- System operating pressure.
- Fuel costs.
- Required steam quality.
- Degree of heat recovery.
- Average steam load.
- Overall costs.
- Amount of returned condensate.

Pretreatment for boilers under 100 psig should be evaluated on a case by case basis, considering the above variables. Sodium zeolite softening is generally used for boilers between 100 and 600 psig. Occasionally hot or cold process lime softening is used. For boilers over 600 psig, demineralization is most often employed. Condensate polishing for iron and copper removal is frequently used in high-pressure systems and in systems where return line corrosion control is neither possible nor desirable. The primary objective of most pretreatment systems is reduction of boiler and superheater deposits. Reduced blowdown and return line corrosion are also significant and common objectives. Contaminated condensate is often pretreated to enable recovery of waste heat and removal of impurities prior to return to the feedwater.

5.2.2 Deaerating Feedwater Heaters. To remove dissolved gases, deaerating heaters increase feedwater temperature by direct contact with low-pressure exhaust steam. Most modern deaerating feedwater heaters include storage tanks to hold heated, deaerated boiler feedwater. These tanks are usually sized to hold sufficient water for 10 minutes of plant operation at maximum load. The storage section is a suitable place to introduce chemicals, such as oxygen scavengers, that require adequate mixing and retention time before water is fed to the boilers. It is important to note that some chemicals, such as volatile amines, will be lost to the atmosphere if added to the deaerators.

There are several ASTM procedural guidelines for properly sampling and testing the effluent of a deaerator in the field for trace oxygen levels. A simplified procedure is merely to construct a small cooling coil from 1/8" diameter copper tubing. The tubing can be attached to a site glass, thermometer port or other drain fitting on the storage section of the deaerator assembly. The cooling coil should end with a valve to restrict the flow sufficiently to prevent flashing. The cooling coil can be immersed in a large bucket of ice water in the event that a cooling water jacket is not available for the copper tubing.

A sample jar should be filled with the copper tube extending down to its bottom face. The jar should be allowed to overfill several times its volume before conducting any analysis. Any bubbles of air flowing through or remaining within the jar will significantly compromise the validity of the test.

The analysis can be conducted by either an expensive trace dissolved oxygen meter or an inexpensive vacuole test. The vacuoles are small glass ampules that are packaged with the necessary reagents and then evacuated of all air. The end of the glass ampule is inserted beneath the surface of the deaerated water sample and then broken. Only water flows into the ampule and the reagents then change color with the presence of dissolved oxygen in the water. The extent of color change can be measured very accurately in a portable spectrophotometer or estimated with a hand held color comparator.

These vacuole test kits are available from Chemetrics, Inc. in Calverton, Virginia @ (703) 788-9026 or HACH Chemical Company of Loveland, Colorado @ (303) 669-3050.

Excessive levels of dissolved oxygen (> 50 ppb) could indicate a variety of problems to include: 1) insufficient venting steam, 2) corroded trays, 3) poor misting action from the spray nozzles, 4) failed baffles, 5) improperly positioned or inoperative pilot control valves, 6) hydraulic overload of the deaerator, and other miscellaneous causes.

   5.2.3 Economizers.   Hot flue gases discharged to the stack constitute the greatest single loss of heat in a fired boiler. An economizer is a heat exchanger placed in the gas passage between the boiler and stack, designed to recover waste heat from combustion products. Generally, a 1-percent increase in efficiency is realized for every 10° to 11°F increase in feedwater temperature. Most modern economizers are constructed of steel, although cast iron is used when corrosion is a consideration, due to condensation of sulfuric or nitric acid in the exhaust. The waterside of an economizer is an extension of the boiler feedwater line. Higher temperature, however, increases likelihood of corrosion and deposition. Accordingly, in systems with economizers, feedwater treatment must be more carefully administered and more extensive. Where economizers are used, mechanical and chemical deaeration are essential. Deaerator performance should be checked regularly. Dissolved oxygen test samples should be taken (with the chemical oxygen scavenger omitted during the tests). Because air can be drawn into the feedwater pump through worn packing under certain inlet temperature and pressure conditions, samples should be taken upstream from feedwater pumps.

5.2.4 Blowdown Systems. Blowdown is removal of a small portion of boiler water from the system to limit concentration of dissolved and suspended solids. Continuous surface blowdown offers the most economical and consistent control of either total dissolved solids or any specific dissolved solid. Automatic control of continuous blowdown can be accomplished by using a conductivity monitor to activate a blowdown control valve. Such devices increase economy since they provide control to a preset point, avoiding waste of water, fuel, and treatment chemicals that accompany unnecessarily high blowdown rates.

Settled sludge still should be removed by occasional manual bottom blowdown. In systems using hard water for boiler makeup, where suspended solids are the determining factor for cycles of concentration, manual blowdown can be used alone. Frequent manual blowdowns of short duration are more effective in sludge removal than occasional blowdowns of long duration.

Blowdown from any boiler, whether intermittent manual bottom drum, purge, or continuous surface, is hot, pressurized fluid. Special provisions are required for safe and efficient blowdown discharge. Sudden reduction of pressure causes flashing of some portion of fluid to lower pressure steam. For safety, this phase change should occur in an enclosed vessel, or flash tank. For low-pressure heating boilers, flashed steam is vented safely to atmosphere, while cooled blowdown is discharged. For most boilers operating at 100 psig or more, where flashing can occur at 5 psig or greater, flash steam is recovered for use in the system. Such steam is typically used to preheat boiler feedwater in the deaerator.

Heat exchangers can also be connected between the make-up water and the blowdown discharge. Engineering calculations are necessary to properly select and specify such equipment. Excessive cooling of the discharged blowdown can result in very rapid scaling of associated piping, valves and heat exchanger surfaces.

5.2.5 Boilers. Modem subcritical boilers are firetube or watertube. Operating pressure, capacity, and boiler efficiency vary over a considerable range for each type, although firetube designs are generally limited to less than 10,000 pounds per hour and to less than 250 psig steam pressure. Watertube boilers range in capacity up to several million pounds per hour with temperatures up to 1,050°F at supercritical pressures. In general, watertube boilers require higher water purity than firetube units. Almost all firetube boilers manufactured today are shop fabricated, packaged units, of design similar to the Scotch type (Figure 5-2). Firetube boilers are characterized by an ability to produce steam at a variety of temperatures and pressures. Design advances have led to very high heat release and heat absorption rates. Therefore, firetube boilers are highly susceptible to corrosion and deposition on internal surfaces. In watertube boilers, water is converted to steam inside the tubes, while hot gases pass on the outside. Tubes are interconnected to common water channels,
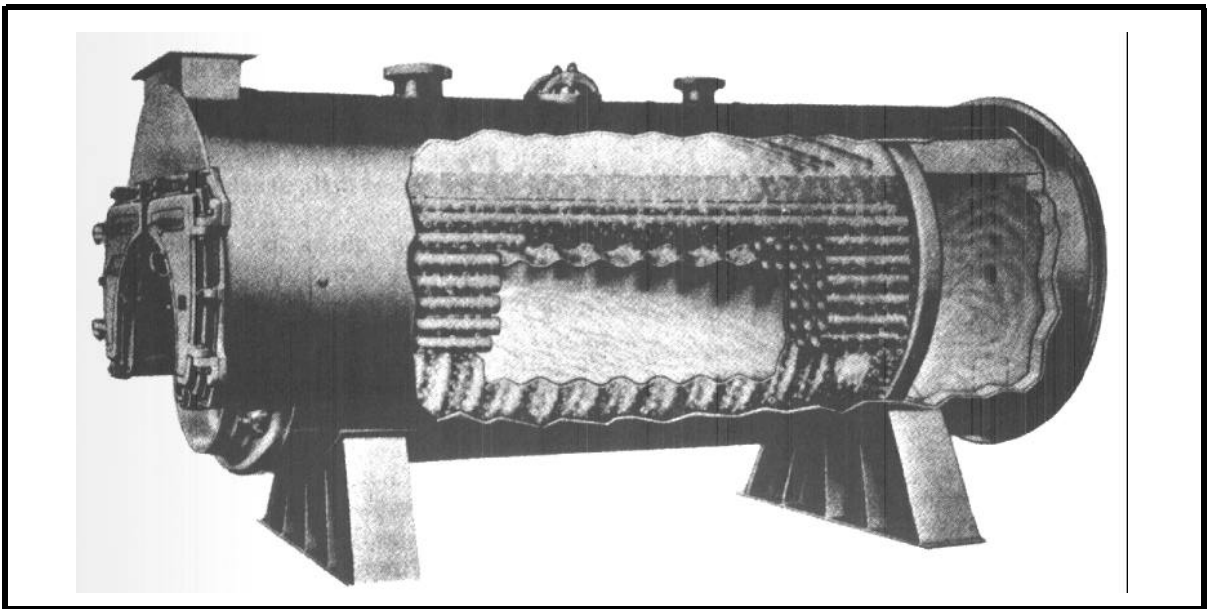
FIGURE 5-2
Scotch-Type Firetube Boiler
(Courtesy Drew Chemical Company

or drums, and to steam outlets. Tube banks are generally constructed with a
series of baffles that lead combustion gases across heating surfaces to obtain
maximum heat absorption. Watertube boilers are available in a wide range of
designs that vary in operating pressure, capacity, quality of steam produced, type
of fuel, and installation and start up costs. While most water-tube boilers
operate by natural circulation, some use pump-induced, forced circulation.
Natural circulation is created by the difference in density between steam and
water. In tubes generating steam, the mixture of steam and water has a lower
density than the water in nongenerating tubes. Thus, in a boiler circuit, flow of
steam and water is upward in hot generating tubes, downward in cool non-
generating tubes. A simple boiler circuit (Figure 5-3) consists of an upper drum
(steam drum) and a lower drum (mud drum) connected by tubes. Steam-
generating tubes located in the hottest area of the boiler, where combustion
gases first pass, are called risers. Risers carry the steam-water mixture upward
to the upper drum where steam is released. Water then flows from the upper
drum through cooler tubes, called downcomers, to the lower drum. In a control-
led, or forced circulation boiler, a circulating pump draws suction from a few
large downcomer tubes and discharges into headers supplying the generating
tubes. This design allows for smaller diameter generating tubes and more intri-
cate tube circuits. In natural and forced draft units, proper circulation is neces-
sary for operation of a watertube boiler. As the steam-water mixture flows
through boiler tubes, it cools tube metal that receives heat from combustion
gases. If circulation is inadequate, boiler tubes will overheat and eventually fail.

Watertube Boiler Designs. Watertube boilers are manufactured in a variety of
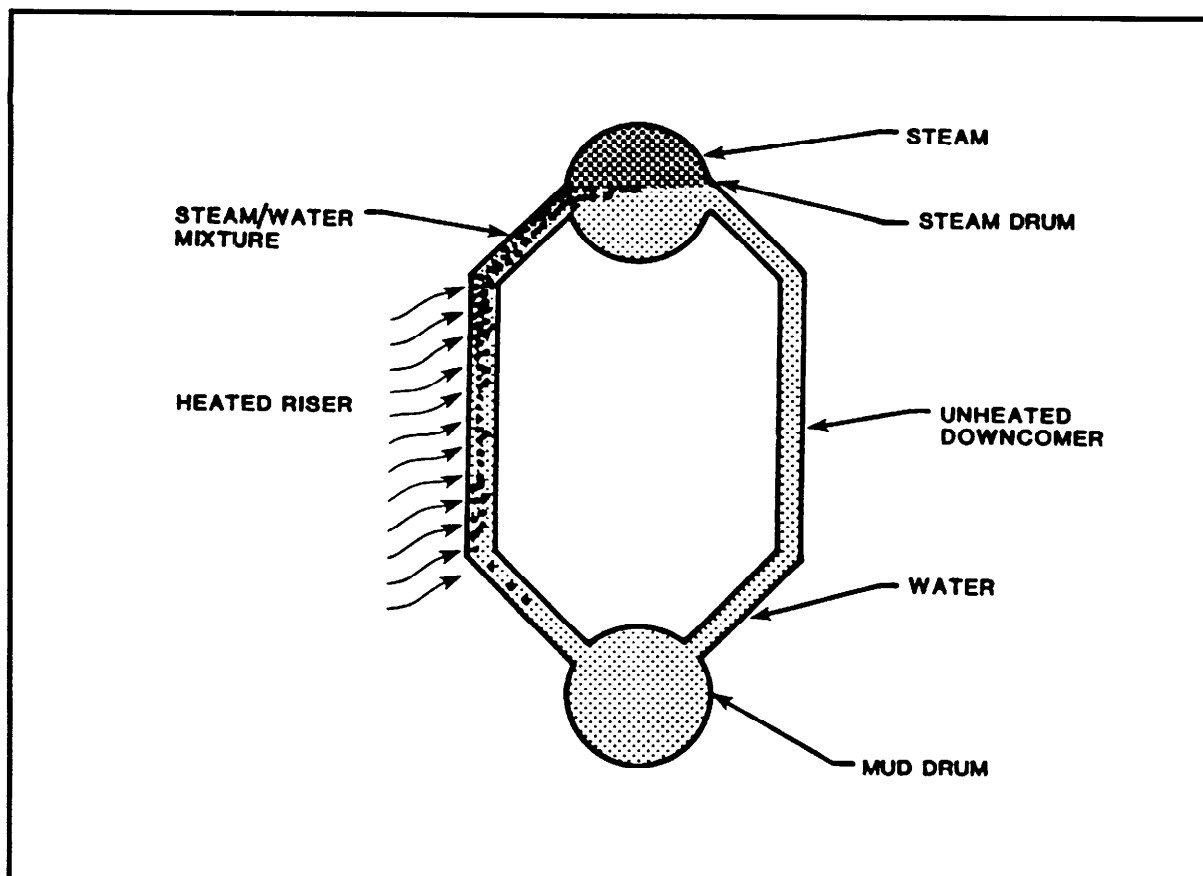
FIGURE 5-3
Simple Watertube Circuit
(Courtesy Drew Chemical Company)

designs. Designs differ in arrangement of steam and mud drums, and in the path of combustion gases. A D-type boiler design is shown in Figure 5-4. Physical size and capacity of packaged water-tube boilers is limited primarily by shipping restrictions from point of manufacture to point of delivery. Thus, field-erected watertube boilers are usually employed when steam capacity requirements exceed 200,000 pounds per hour. Field-erected boilers usually consist of two drums connected by risers and downcomers positioned above and to the side of a relatively large radiant furnace, lined with waterwall tubes. Since the furnace releases considerable heat, waterwall tubes are responsible for a significant portion of the steam generated. Field-erected units usually include auxiliary equipment such as economizers, air heaters, and superheaters. Packaged boilers can also be equipped with these auxiliaries.

5.2.6 Steam Drum Internals.   The main purpose of the steam drum in a watertube boiler is to provide sufficient volume to separate steam from water. This is usually assisted by addition of mechanical devices in the drum, causing steam to travel greater distances on its path to the outlet header, and ef-

5-7
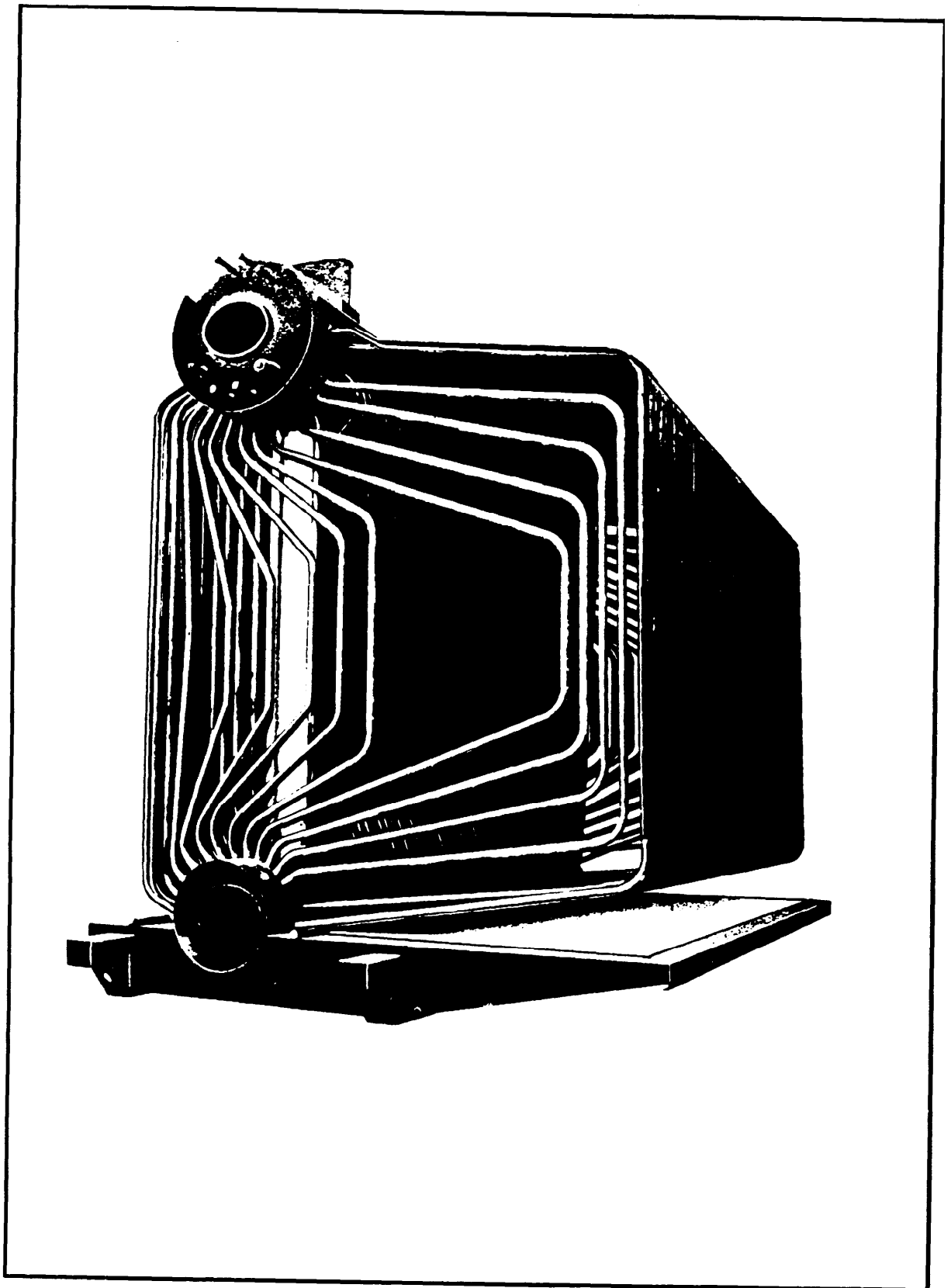
FIGURE 5-4
D-Type Boiler

fecting separation by differences in inertia. Such devices reduce the mechanical entrainment of water droplets (mechanical carryover) but do not affect vaporous materials in the steam (volatile carryover). Requirements for steam purity vary widely. As a rule, highest purity is required when steam is used to drive turbines. This usually coincides with requirements for high-pressure boiler operation. In smaller, low-pressure boilers (firetube and watertube), elaborate steam separating devices generally are not used. Baffles, screens, and dry pipes installed above water level in the steam drum are used to reduce mechanical entrainment. Modern, high-pressure units require high-purity steam to prevent deposit formation in superheaters and on turbine blades. The problem of designing efficient drum internals increases with pressure. This is primarily caused by changes in the physical properties of water and steam when temperature is increased. While separation equipment has a marked effect on carryover, other factors are also significant. Carefully selected and controlled internal water treatment, plus pretreatment of feedwater, reduce carryover tendency of boiler water.

5.2.7 Superheaters.   Saturated steam, leaving drums of large boilers, is commonly directed through superheater sections before leaving the boiler. A superheater heats steam, above saturation temperature. Superheated steam contains more energy than saturated steam, and provides added driving potential for turbines with very little increase in fuel consumption. Superheater tubes have steam on one side and hot combustion gases on the other. It is important to maintain steam flow in each superheater tube to avoid overheating. Operation above design temperature for the tube metal employed can result in excessive iron oxide formation inside the tube, even though it is not high enough to result in tube failure. This oxide tends to spall during temperature changes, associated with start up and shutdown, and can cause severe abrasion of the steam turbine nozzle block and first stage blades. It is important that tube surfaces be clean internally and externally, and that carryover be minimized. Otherwise, internal deposits of boiler water solids can result in overheating and possible failures. A common superheater design in modem boilers is the pendant, nondrainable type. In such systems, whenever the boiler is shut down, lower bends of each pass retain condensate produced from residual steam in the superheater. On start up, this condensate must be carefully reevaporated and steam released through a vent. During layup periods or boiler cleanings, superheaters must be filled with high-purity water containing a neutralizer and an oxygen scavenger. Alternatively, the superheater can be purged with an inert gas such as nitrogen. Under no circumstances should a nondrainable superheater be filled with water containing nonvolatile dissolved solids. These solids will deposit on superheater tube surfaces and will be very difficult to remove by flushing or chemical cleaning. Where reheaters are employed, the same precautions apply.

5.2.8 Turbines.   Turbines are rotary devices driven by steam. The largest turbines are used to drive generators that produce electric power. In most units, energy in the steam is used to produce power before exhaust steam is condensed and returned as feedwater. In some steam/electric utility plants, and in many industrial power plants, only part of the steam energy is used to generate electricity. The remaining energy, as lower-pressure steam, is used in a steam distribution system for heating or other purposes. The economy and performance of a turbine depend on design and construction of turbine blades. Turbines are built with very close tolerances; stationary and moving parts have little clearance. Any vibration has a destructive effect. Of special concern is erosion of turbine blades by condensation. Deposits and erosion distort turbine blades and nozzle shape, producing rough surfaces and increasing steam flow resistance. Heavy blade deposits can cause turbine unbalance, producing intolerable vibration. Generally, turbine deposits are caused by carryover or corrosion. Nonselective boiler water carryover can be caused by a high level of total solids in boiler water, high boiler water alkalinity, feedwater quality (periodic contamination of some nature), and mechanical difficulties (steam separator failure, rapid load variation, poor water level control). Generally, deposits that form on turbine blades as a result of carryover can be rinsed from blades with condensate formed during low load or unloaded operation. Selective carryover is a more serious problem. In this case, one constituent is vaporized in the steam. In high-pressure units, silica is the most common constituent carried over by vaporization. Silica volatility, at any pressure, is dependent on silica concentration and pH of the boiler water. Pure silica deposits are hard and glassy and cannot be removed by condensate. They are usually removed by either sandblasting or gritblasting. When sufficient nonselective carryover accompanies volatile silica, soluble sodium silicate deposits can form Corrosion caused by insufficient feedwater treatment when the system is out of service, or by improper boiler and turbine layup procedure, can be a serious problem in turbines. Failure to observe good out-of-service (layup) procedures can make partial or complete turbine reblading necessary.

5.2.9 Condensers.   Exhaust steam leaving a turbine should be used in the plant or be condensed before it reenters the boiler. Condensers create a vacuum as steam is condensed. The vacuum creates reduced back pressure on the turbine and greatly increases unit efficiency. A surface condenser is most commonly used. It consists of a closed vessel filled with tubes. Cooling water flows through the tubes, while steam flows around them. Coolant flowing through tubes can be used on a once-through basis or recirculated through a cooling tower. Condensate flows out the base of the condenser to a hot well where it is ready to reenter the water/steam cycle. Condensation gases and air that have entered through in leakage are removed by ejectors or vacuum pumps from a special air removal section of the condenser. Air and oxygen removal reduce back pressure on the turbine, and limit iron and copper corrosion in the preboiler system. Ammonia removed by steam jet air ejectors will redissolve in

jet condenser condensate and will recycle if this condensate is returned to the main turbine condenser. Such recycling can build ammonia concentrations that, if oxygen is present, become corrosive to copper or brass condenser tubes in the air removal section. Injection of catalyzed hydrazine can be beneficial when such problems occur. In such cases, jet condenser condensate should be handled separately. In addition to corrosion problems, condensers are subject to erosion and vibration on the steam side. Condensate droplets in exhaust steam, at sufficiently high velocity, can erode portions of the top two rows of tubing to failure. Shields or grids of a more resistant alloy are placed on or ahead of the first row of tubing to prevent failure by fretting and fatigue. Factors responsible are inlet steam velocity and excessive distance between tube support plates based on the material, diameter, and wall thickness of the tubing used. Elimination of vibration in condensers often requires reducing turbine capacity.

5.2.10 Heating and Process Equipment.   Central stations and closed heating systems are two common configurations that use steam generated in closed, noncontaminating equipment. All steam is condensed and returned to the boiler as feedwater. In such systems, very little water is lost. Consequently, need for treated makeup water is minimized. A great number of plants use steam for process equipment heating where condensate is not recoverable. This is often caused by absorption of the steam by the product or by its contamination during contact with the product. In other cases, condensate is discarded because collection and return is uneconomical. Such systems require large amounts of makeup water.

5.3 WATER TREATMENT OBJECTIVES. Boiler feedwater, regardless of the type and extent of external treatment, can contain contaminants that cause deposits, corrosion, and carryover.

5.3.1 Deposits.   Deposits directly reduce heat transfer, causing higher fuel consumption, high metal temperatures, and, eventually, failures. Deposits, although most serious in the boiler, may also cause problems in preboiler and afterboiler systems.

5.3.2 Corrosion.   Corrosion results in failure at the point of attack and produces metal oxide contamination that can cause deposits elsewhere. Problems of deposit formation and corrosion are so closely related that both should be effectively corrected or prevented to achieve satisfactory treatment.

5.3.3 Carryover.   Carryover results in deposits, corrosion, and/or erosion problems in the superheater, turbine, and condensate systems. Serious losses inefficiency, especially when superheated steam is used for power generation, result from loss of superheat, turbine blade deposits, erosion, or corrosion.

5-11

Even extremely low levels of carryover can cause failures and complete system outages.

5.3.4 Objectives.   The three main objectives of boiler water treatment are to prevent formation of deposits, reduce corrosion of metals, and prevent boiler water carryover. All parts of the steam-water system are interdependent. In deciding on treatment to use, the entire system should be considered. Tables 5-1A through 5-1D contain recommended limits for water quality as a function of boiler pressure and are usual standards for boiler and feedwater quality limits. These limits are set by an ASME subcommittee. There are other considerations, such as corrosion and deposit formation, in establishing boiler water limitations. Modem watertube boilers reach heat flux rates that greatly exceed those of earlier boilers. This has resulted in the need for the new guidelines provided by the ASME.

TABLE 5-1A

ASME Suggested Water Quality Limits

Boiler Type: Industrial watertube, high-duty, primary fuel-fired, drum type
Makeup Water Percentage: Up to 100% of feedwater
Conditions: Includes superheater, turbine drives, or process restriction on steam purity
Saturated Steam Purity Target[1]

Drum Operating Pressure (psig)[2]	0-300	301-450	451-600	601-750	751-900	901-1,000	1,001-1,500	1,501-2,000
Feedwater[a]								
Dissolved oxygen (mg/l O_2) measured before oxygen scavenger addition[4]	<0.04	<0.04	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Total iron (mg/l Fe)	≤0.100	≤0.050	≤0.030	≤0.025	≤0.020	≤0.020	≤0.010	≤0.010
Total copper (mg/l Cu)	≤0.050	≤0.025	≤0.020	≤0.020	≤0.015	≤0.015	≤0.010	≤0.010
Total hardness (mg/l as $CaCO_3$)	≤0.300	≤0.300	≤0.200	≤0.200	≤0.100	≤0.050	-- Not Detectable --	
pH range @ 25°C	7.5-10.0	7.5-10.0	7.5-10.0	7.5-10.0	7.5-10.0	8.5-9.5	9.0-9.6	9.0-9.6
Chemicals for preboiler system protection	-------------------- Use only volatile alkaline materials --------------------							
Nonvolatile TOC (mg/l C)[5]	<1	<1	<0.5	<0.5	<0.5	--- As low as possible, <0.2 ---		
Oily matter (mg/l)	<1	<1	<0.5	<0.5	<0.5	--- As low as possible, <0.2 ---		
Boiler Water								
Silica (mg/l as SiO_2)	≤150	≤90	≤40	≤30	≤20	≤8	≤2	<1
Total alkalinity (mg/l as $CaCO_3$)	<350[6]	<300[6]	<250[6]	<200[6]	<150[6]	<100[6]	---Not Specified[7]---	
Free hydroxide alkalinity (mg/l as $CaCO_3$)[8]	-------------------- Not Specified --------------------						- Not Detectable[7] -	
Specific conductance (µS/cm) (µmho/cm) @ 25°C without neutralization	<3,500[9]	<3,000[9]	<2,500[9]	<2,000[9]	<1,500[9]	<1,000[9]	≤150	≤100

TABLE 5-1A Notes

1. Steam purity achievable depends upon many variables, including boiler water total alkalinity and specific conductance as well as design of boiler, steam drum internals, and operating conditions (note 5). Since boilers in this category require a relatively high degree of steam purity, other operating parameters should be set as low as necessary to achieve this high purity for protection of superheaters and turbines or to avoid process contamination.

2. With local heat fluxes of 150,000 Btu/hr/ft², use values for the next higher pressure range.

3. Boilers below 900 psig with large furnaces, large steam release space and internal chelant, polymer, or antifoam treatment can sometimes tolerate higher levels of feedwater impurities than those in the table and still achieve adequate deposition control and steam purity. Removal of these impurities by external pretreatment is always a more positive solution. Alternatives should be evaluated in terms of practicality and economics on an individual basis.

4. Values in table assume existence of a dearator.

5. Nonvolatile Total Organic Compounds (TOC) is the organic carbon not intentionally added as part of the water treatment regimen.

6. Maximum total alkalinity consistent with acceptable steam purity. If necessary, should override conductance as blowdown control parameter. If makeup is demineralized water at 600 psig to 1,000 psig, boiler water alkalinity and conductance should be that in table for 1,001 to 1,500 psig range.

7. Not detectable. In these cases refers to free sodium or potassium hydroxide alkalinity. Some small variable amount of total alkalinity will be present and measurable with the assumed congruent or coordinated phosphate/pH control or volatile treatment employed at these high-pressure ranges.

8. Minimum level of OH' alkalinity in boilers below 900 psig must be individually specified with regard to silica solubility and other components of internal treatment.

9. Maximum values often not achievable without exceeding suggested maximum total alkalinity values, specially in boilers below 900 psig with 20% makeup of water whose total alkalinity is 20% of TDS naturally or after pretreatment by lime/soda, or sodium cycle ion exchange softening. Actual permissible conductance values to achieve any desired steam purity should be established for each case by careful steam purity measurements. Relationship between conductance and steam purity is affected by too many variables to allow its reduction to a simple list of tabulated values.

TABLE 5-1B

ASME Suggested Water Quality Limits

Boiler Type: Industrial watertube, high-duty, primary fuel-fired, drum type
Makeup Water Percentage: Up to 100% of feedwater
Conditions: No superheater, turbine drives, or process restriction on steam purity

Saturated Steam Purity Target[1]:   1.0 mg/L (ppm) TDS maximum

Drum Operating Pressure (psig)	0 - 300	301 - 600
Feedwater[2]		
Dissolved oxygen (mg/L O_2) measured before chemical oxygen scavenger addition4	0.04	0.04
D.O. after chemical oxygen scavenger addition	0.007	0.007
Total iron (mg/L Fe)	0.10	0.05
Total copper (mg/L Cu)	0.05	0.025
Total hardness (mg/L as $CaCO_3$)	0.5	0.3
pH range @ 25°C	7.0-105	7.0-10.5
Nonvolatile TOC (mg/L C)	1	1
Oily matter (mg/L)	1	1
Boiler Water		
Silica (mg/L as SiO_2)	150	90
Total akalinity (mg/L as $CaCO_3$)	1,000[6]	850[6]
Free hydroxide alkalinity (mg/L as $CaCO_3$)[7]	-- Not Specified --	
Specific conductance (uS/cm) (umho/cm) at 25°C without neutralization	8,000[6]	6,500[6]

TABLE 5-1B. Notes

1. Target value represents steam purity that should be achievable if other tabulated water quality values are maintained. The target is not a guarantee of boiler performance.

2. Boilers with relatively large furnaces, large steam release space and internal chelant, polymer, or antifoam treatment can often tolerate higher levels of feedwater impurities than those in the table and still achieve adequate deposition control and steam purity. Removal of these impurities by external pretreatment is always a more positive solution. Alternatives should be evaluated as to practicality and economics in each individual case. The use of some dispersant and antifoam internal treatment is typical in this type of boiler operation so it can tolerate higher feedwater hardness than the boilers in Table 5-1A.

3. Value in table assumes existence of a deaerator.

4. Chemical oxygen scavenging should be provided in all cases, but especially if mechanical deaeration is nonexistent or inefficient.

5. Nonvolatile TOC is that organic carbon not intentionally added as part of the water treatment regimen.

6. Alkalinity and conductance values consistent with steam purity target. Practical limits above or below tabulated values can be established for each case by careful steam purity measurements.

7. Minimum level of OH$^-$ alkalinity should be individually specified with regard to silica solubility and other components of internal treatment.

TABLE 5-1C

ASME Suggested Water Quality Limits

Boiler Type: Industrial firetube, high-duty, primary fuel-fired
Makeup Water Percentage: Up to 100% of feedwater
Conditions: No superheater, turbine drives, or process restriction on steam purity
Saturated Steam Purity Target[1]: 1.0 mg/L (ppm) TDS maximum

Drum Operating Pressure (psig)	0-300
Feedwater[2]	
Dissolved oxygen (mg/L O_2) measured before chemical oxygen scavenger addition4	0.04
Dissolved oxygen (mg/L O_2) measured after chemical oxygen scavenger addition4	0.007
Total iron (mg/L Fe)	0.1
Total copper (mg/L Cu)	0.05
Total hardness (mg/L as $CaCO_3$)	1.0
pH range @ 25°C	7.0-10.5
Nonvolatile TOC (mg/L C)[5]	10
Oily matter (mg/L)	1
Boiler Water	
Silica (mg/L as SiO_2)	150
Total alkalinity (mg/L as $CaCO_3$)[7]	700[6]
Free hydroxide alkalinity (mg/L as $CaCO_3$)[7]	Not Specified
Specific conductance (uS/cm) (umho/cm) at 25°C without neutralization	7,000[6]

TABLE 5-1C. Notes

1. Target value represents steam purity that should be achievable if other tabulated water quality values are maintained. The target is not a guarantee of boiler performance.

2. Firetube boilers of conservative design, with internal chelant, polymer, or autifoam treatment can often tolerate higher levels of feedwater impurities than those in the table (0.5 mg/L Fe, 0.2 mgL Cu, 10 mg/L total hardness) and still achieve adequate deposition control and steam purity. Removal of these impurities by external pretreatment is always a more positive solution. Alternatives should be evaluated as to practicality and economics in each individual case.

3. Value in table assumes existence of a deaerator.

4. Chemical deaeration must be provided in all cases, but especially if mechanical deaeration is nonexistent or inefficient.

5. Nonvolatile TOC is that organic carbon not intentionally added as part of the water treatment regimen.

6. Alkalinity and conductance guidelines consistent with steam purity target. Practical limits above or below tabulated values can be established for each case by careful steam purity measurements.

7. Minimum level of OH$^-$ alkalinity should be individually specified with regard to silica solubility and other components of internal treatment.

TABLE 5-1D

ASME Suggested Water Quality Limits

Boiler Type: Industrial, coil type, watertube, primary fuel-fired rapid steam generators
Makeup Water Percentage: Up to 100% of feedwater
Total Evaporation: Up to 95% of feedwater
Steam to Water Ratio (volume to volume): Up to 4,000 to 1
Saturated Steam Purity Targets: See table

Operating Pressure (psig) Steam Purity Targets	**0-300**	**301-450**	**451-600**	**601-900**
Specific conductance @ 25°C (uS/cm) (umho/cm)	50	24	20	0.5
Dissolved solids (mg/L)	25	12	10	0.25
Silica (mg/L as SiO_2)[2]				0.003
Feedwater* Dissolved oxygen (mg/L O_2) measured before oxygen scavenger addition[4]	0.2	0.2	0.2	0.007
Dissolved oxygen (mg/L O_2) measured after oxygen scavenger additions	0.007	0.007	0.007	0.003
Total iron (mg/L Fe)	1.0	0.3	0.1	0.05
Total copper (mg/L Cu)	0.1	0.05	0.03	0.02
Total hardness (mg/L as $CaCO_3$)	1.0	0.7	0.5	Not Detect
pH range @ 25°C	9.0-9.5	9.0-9.5	8.8-9.2	8.8-9.2
Chemicals for preboiler system protection. Boiler Water[6]	Use only volatile alkaline materials			
Silica (mg/L as SiO_2)	150	100	60	30
Total alkalinity (mg/L as $CaCO_3$)	800	600	500	200
Hydroxide: alkalinity (mg/L as $CaCO_3$)[8]	300	200	120	60
Specific conductance (uS/cm) (umho/cm) @ 25°C without neutralization	8,000	6,000	5,000	4,000

TABLE 5-1D. Notes.

1. Demineralization of makeup water recommended.

2. Tabulated values based on assumption of no superheaters or turbine drives. If steam used for superheat or turbine drives, use values for 901 psig and up. If unit operation approaches superheat conditions within coil, use values for 601 to 900 psig range to avoid silica deposition on near-dry surfaces. The target is not a guarantee of boiler performance.

3. Feedwater is defined as makeup water plus condensate, other than separator returns.

4. Values in table assume existence of a deaerator.

5. Chemical deaeration with catalyzed oxygen scavenger is necessary in all cases because feedwater temperature limits imposed by manufacturers of coil type steam generators preclude efficient mechanical deaeration. Feed of chemical oxygen scavenger should be sufficient to maintain a detectable residual in the boiler water. For those units that include steam separator/water storage drums and recirculate a substantial amount of boiler water, oxygen scavenger residuals should be maintained in higher ranges typical of those employed for drum type boilers.

6. Boiler water analyses determined on separator discharges or on storage drum sample.

7. Suggested values vary with operating pressure decreasing proportionally as pressure increases up to 2,500 psig.

8. Hydroxide alkalinity in mg/L as $CaCO_3$ should be maintained at a minimum of 1.7 times silica in mg/L as SiO_2 to keep silica soluble and avoid complex silicate deposits. Most coil type steam generators do not employ scale control internal treatment chemicals to assist in prevention of such deposits

5.4 BOILER SYSTEM PROBLEMS.

5.4.1 Carryover of Boiler Water. Maintenance of steam purity is of extreme importance for plant operation. Presence of small quantities of inorganic salts in water carried over from the boiler to the steam can cause superheater failures, loss of turbine efficiency, failure of steam traps, and other related problems. This can also increase potential for corrosion and/or erosion in steam condensate systems. In addition, carryover can cause contamination in direct steam use processes. In steam generators equipped with superheaters, carryover can be serious because materials carried over can form deposits in the superheater, resulting in overheating and subsequent tube failures. Solids concentrations in boiler water greater than 1.0 ppm will cause superheater deposits that can form at concentrations in the steam as low as 0.1 ppm. Steam purity is essential when turbines follow superheaters. Carryover of dissolved material, from boiler water to steam, is caused by entrainment of small droplets of boiler water leaving the drum and by volatilization of dissolved salts that are soluble in steam. Mechanical entrainment is a function of design and method of operation of steam separators in the boiler. Conditions that produce foaming increase the presence of droplets in the steam separating equipment. The entrainment process may be divided into two categories, priming and foaming. Priming usually results from a sudden reduction in boiler pressure caused by a rapid increase in the boiler steam load. This causes steam bubbles to form throughout the mass of water in the boiler. Increased water volume raises the level in the drum, flooding separators or dry pipe. Priming may also result from an excessively high water level following a rapid load reduction caused by control failure. Foaming is a buildup of bubbles on the water surface in the steam drum This reduces the steam release space and, by various mechanisms, causes mechanical entrainment. Mechanical entrainment is usually controlled through proper design and efficient operation, supplemented by use of antifoam agents in situations where foaming becomes a problem.

5.4.2 Design Considerations. The steam drum of any boiler should be designed with sufficient volume to allow separation of water before the steam leaves the boiler. For a discussion on steam separators, refer to MO-209, **Maintenance of Steam, Hot Water, and Compressed Air Distribution Systems.** Steam drums may contain baffles, screens, mesh, chevron, or centrifugal separators to improve separation. Each element should be kept tight and clean; a 1/4-inch gap between sections of cover baffles over the generating tubes can cause water to bypass separators and negate their operation. Similarly, presence of deposits on screens or mesh can prevent the devices from functioning properly. It is essential for all drum components to be inspected regularly and maintained in proper working order. Mechanical entrainment is rarely uniform along the length of a drum. Any sampling technique used for monitoring steam purity should take this into account and provide for collection from a variety of points in the drum.

5.4.3 Operational Effects. Since size of a steam drum is fixed., operating water level determines the vapor/liquid separation space. When water level is excessively high, separation area and volume are reduced and continuous entrainment can result. Lowering operating water level can correct this situation. Operation below mid-drum level should be evaluated carefully because, while steam separation volume is increased, disengagement area is reduced. In addition, angle and point of entry of the steam-water mix from generating tubes is important. Mechanical carryover from boilers is frequently caused by operation at steam generation loads exceeding design rating. This can occur continuously or intermittently as a result of sudden process steam demands. Load surges cause a sudden lowering of pressure in the drum, with resultant violent boiling and discharge of boiler water into the steam release space. Uneven fuel firing can cause excessive localized steam generation and result in carryover, even when other operational aspects are normal. Where carryover is the result of foaming, various steps including use of antifoam agents can correct the problem.

5.4.4 Chemical Considerations. Separation of water droplets from steam is a function of boiler water surface tension. Surface tension affects the size of steam bubbles formed on the heat transfer surface and the ease with which they coalesce and collapse. Lower surface tension results in formation of small bubbles and tends to stabilize them in the steam drum, causing an excessive quantity of small droplets of boiler water to enter the final stages of the steam separating equipment. Components in boiler water that can increase potential for mechanical entrainment include: alkalinity, dissolved solids, suspended solids, and organic surfactants such as saponified oils and synthetic detergents. A program to control chemistry of boiler water should regulate these components. Since entrainment increases with operating pressure, TDS must be reduced as pressure increases to maintain a constant steam purity.

Alkalinity. Total alkalinity of boiler water is a function of makeup water alkalinity and alkalinity of treatment chemicals added for internal deposit or corrosion control along with their cycles of concentration in the boiler. Makeup water alkalinity is usually in the form of carbonates and bicarbonates, which decompose at boiler temperature to release carbon dioxide and form hydroxide alkalinity. Alkaline treatment chemicals are caustic soda and soda ash. Alkalinity can be controlled in boiler water by increased blowdown, external dealkalization of makeup water, ion exchange on the hydrogen cycle, dealkalization by acid addition, or elimination of alkaline chemical feed. The most effective and economical method is external treatment of makeup water. External treatment often produces an additional benefit by reducing total dissolved solids.

Total Dissolved Solids (TDS). TDS concentration is usually determined by conductivity measurements on a neutralized sample of boiler blowdown water and is often read directly as micromhos/cm (umhos/cm) of specific conductance.

TDS level is controlled in boiler water primarily by varying the amount of surface or continuous blowdown Careful selection of chemicals can minimize dissolved solids in boiler water. It is often economically desirable to reduce boiler water solids by pretreating makeup water and by returning a large percentage of condensate. If the boiler is not equipped with automatic blowdown, intermittent, manual blowdown should be performed.

Suspended Solids. Suspended solids can be present in boiler water as a result of precipitation of boiler sludge, suspended matter carried in feedwater, or corrosion products. Possible corrective measures are control of formation and concentration of suspended matter, removal of suspended solids from feedwater, internal treatment with a dispersant or antifoam agent, or minimizing corrosion products by condensate polishing or improved corrosion control.

5.4.5 Use of Chemical Antifoams. Frequently, chemicals are added to boiler water to counteract effects of high TDS, alkalinity, suspended solids and oil or other organics, and to allow operation without unacceptable chemical carryover. Such a program may be more economical than increased blowdown or additional external treatment. Occasionally, use of a chemical antifoam agent is necessary to operate a boiler without gross entrainment. Chemical antifoams frequently reduce fuel consumption by permitting lower blowdown rates while producing high-quality steam. Polyglycols and polyamides are chemicals most often employed as antifoam agents. Of these two, polyglycols have been most successful and accepted. They are fed directly to the boiler or to the feedwater line in low dosages, and are often blended with other internal treatment chemicals. In most. foaming situations, controlled use of an antifoam agent will successfully reduce carryover. There are instances where the chemical agent provides no improvement and may even increase carryover. The decision to use an antifoam agent should be made strictly on the basis of steam quality measurements.

5.4.6 Volatile Carryover. When steam is generated at high pressure many solids dissolved in boiler water volatilize, and are carried from the boiler dissolved in steam. This contamination of steam is volatile carryover. These contaminants deposit at any point where temperature conditions allow condensation. Volatile carryover cannot be prevented by mechanical or operational modifications, or by addition of chemical antifoam agents. The only remedy is to limit concentration of volatile solids in boiler water or to vary pH, a factor that influences volatility. Volatile carryover begins to reach significant levels in boilers operating at 600 psig and increases proportionately with pressure. The most important volatile solid is silica, although volatilities of sodium hydroxide, sodium chloride, and sodium phosphate can also reach significant levels, especially at higher pressures and concentrations. Vaporization of dissolved materials such as ammonia, carbon dioxide, hydrogen sulfide, sulfur dioxide,

and morpholine, that are normally gaseous or highly volatile, also occurs. With the exception of ammonia and morpholine, these materials are usually absent in high-pressure boiler systems. Silica can vaporize and deposit on turbine blades at boiler pressures greater than 600 psig. Therefore, its presence is cause for concern when steam is used for turbine drives. It is generally accepted that when steam has 20 parts per billion (ppb) or less silica, it will not deposit on turbine blades; however, when sufficient sodium is present, complex sodium silicates can deposit at concentrations lower than 20 ppb. Iron and copper contamination of steam can be reduced by lowering their concentration in feedwater. Catalyzed hydrazine has been highly effective in reducing pickup of iron and copper.

5.4.7 **Deposition From Steam.** Deposits of boiler water salts can occur in turbines and steam traps, whether carryover is mechanical, volatile, or both. Silica is one of the more volatile salts commonly encountered in boiler water. Its solubility in superheated steam decreases rapidly as temperature and pressure decrease. Silica deposits form as solubility decreases. Deposits in superheaters are caused by mechanical entrainment or contaminated desuperheating water.

5.4.8 **Deposit Removal From Superheaters.** Once carryover deposits form in a superheater, removal is difficult and dangerous. In a drainable superheater, it is possible to fill the system with hot boiler water on shutdown or to backfill with hot condensate from the outlet header. Soaking with either of these waters should dissolve deposits, unless accumulation has completely plugged the tubes. After the soak, the unit is drained, then flushed with high-purity water until effluent conductivity indicates complete removal of dissolved salts. In nondrainable superheaters, the procedure is more complicated because it is nearly impossible to ensure adequate flow through all lines. Backfill from outlet headers or manual flushing of individual tubes from the drum is possible, but the necessary volume of high-pressure, high-purity water is usually not available. It is possible to flood the superheater with hot, high-purity feedwater or condensate after taking the unit out of service and before internal pressure returns to ambient. High-purity water can then be used to flush the superheater once the steam has condensed and all loops are filled with water. Sufficient flushing should take place to ensure that the superheater is free of all deposits. Acid solvent cleaning in nondrainable superheaters is not recommended when deposits are water insoluble, because a potential exists for greater damage from cleaning than would occur by leaving deposits in place.

5.4.9 **Removal of Deposits From Turbines.** Water soluble deposits can be removed from turbine blades by condensate washing, either during operation or when shutdown. This involves removing the load from the turbine but allowing it to spin on saturated steam. If the machine is full-condensing and

can be removed from service intermittently, soluble deposits can be removed by periodic washing before serious accumulation occurs. During removal, care should be taken to avoid damage to the turbine. Specific procedures should be followed closely. Caustic can be added to improve silica removal but will result in loss of large quantities of condensate. Specific conductance and/or silica are monitored in the condenser. Some deposits, particularly silica, that form in turbines are not water soluble. In this case, the cleaning procedure is to open the casing, remove the rotor, and clean the blades mechanically.

 5.4.10 Standby Protection Against Corrosion (Layup). During non-operational periods, protection against corrosion of boilers, auxiliary systems, and other related industrial equipment is essential. Downtime corrosive attack can cause loss of metal. Corrosion products are released from the preboiler section during service shutdowns. During subsequent periods of operation, iron and copper oxides formed by out-of-service corrosion can be transported to boiler heating surfaces. These oxides form deposits and can cause localized attack and tube metal overheating. The history of operational corrosion in power station units and industrial boilers shows that application of effective corrosion control measures during startup and shutdown periods, combined with continuous onstream controls, constitutes sound preventive maintenance. These measures and controls assist in protection of the original investment and extend the useful life of major plant equipment. The key factors affecting downtime corrosion are water, oxygen, and pH. Elimination of moisture, or air, will prevent appreciable corrosion. Dry layups accomplish this goal by eliminating water and by reducing relative humidity to a safe level. Wet layups control corrosion by excluding oxygen and maintaining a high pH level. Layups using nitrogen gas to displace air from the boiler also control corrosion by excluding oxygen. The decision to use wet, dry, or nitrogen gas standby protection depends on duration of the downtime and the degree of availability required of power plant equipment. Wet storage is employed regardless of duration if the boiler is to be kept available for immediate use. Dry storage is usually preferred for long shutdowns. Steam plant shutdowns of 1 month or less are short-term layup; those exceeding 1 month are long-term.

 5.4.11 Short-Term, Wet Standby Protection. Wet layup techniques should be implemented for shutdowns lasting 1 month or less, and in situations requiring immediate availability. During wet storage, dual mechanisms used to protect the equipment are exclusion of oxygen and maintenance of high pH. For boilers with softened feedwater and nondrainable superheaters, wet layup can only be accomplished by blanketing the superheater and the space above normal drum water level with nitrogen. For wet layup of high-pressure boilers, inhibitors used are oxygen scavengers and chemicals to adjust pH. Nitrogen blanketing should be employed if it is necessary to avoid flooding the superheater. Special layup procedures should be followed to protect idle units after

acid cleaning. Ideally, chemical cleaning of a boiler with acidic solvent should be scheduled to make certain that boiler startup can proceed immediately after completion of cleaning. Cleaning includes neutralization, passivation, and inspection. Should a delay of more than 1 or 2 days occur between the end of cleaning and startup, the boiler should be filled with treated feedwater or condensate. When filling a boiler for wet layup, it is desirable for corrosion inhibitors (proportioned to deaerated feedwater) to be fed into the economizer where they remain to afford standby protection. The same wet standby treatment for a boiler is used for the superheater section, with one notable exception; caustic and sulfite cannot be used in nondrainable superheater layup. If wet layup of a nondrainable superheater is necessary, the recommended chemical inhibitors are hydrazine (or catalyzed hydrazine) and ammonia or neutralizing amine (morpholine, cyclohexylamine). This volatile treatment ensures that no deposits are formed in the superheater when the boiler resumes operation. Air ingress can cause exfoliation (a special type of oxidation in feedwater heaters during shutdown). Surface oxidation of hot tubes occurs on startup and shutdown. Exfoliation corrosion can be controlled by methods other than use of alternative metals. Standby can be accomplished by blanketing with inert gas or steam. This excludes oxygen, the source of the problem. Because air entering the system during shutdown is the only source of oxygen, the turbine, feed lines, and heater shell should be blanketed with nitrogen or steam. For some power plants, steam blanketing is more practical than nitrogen pressurization.

When turbines are out of service, they should be kept dry using one or more of the following precautions:

- Tightening the block valve on the inlet steam line.
- Installing two block valves with a drain between them.
- Bleeding heated or dry instrument air into the turbine.
- Following manufacturer's specifications for out-of-service storage.

5.4.12 Long-Term Storage. For shutdowns exceeding 1 month or those involving boilers subject to freezing conditions, dry storage techniques may be required to protect power plant equipment. Dry techniques fall into two general categories: open and closed. Elimination of all moisture is the primary objective in dry standby, because as long as the boiler and other metal surfaces remain dry, no significant corrosion can occur. Air in contact with moisture is extremely corrosive and water leakage into the unit or sweating of surfaces must be avoided. The boiler should be drained completely, thoroughly cleaned on both fireside and waterside, and inspected. All internal surfaces should be dried. During dry storage, the boiler should be inspected for condensation. The success of dry layup is dependent on leak-free, nonreturn valves, feedwater valves, and blowdown valves, when connected to an operating system. Several different or combined treatments can be applied to an idle boiler stored dry and

sealed. Although this approach can be effective if rigorously implemented, it presents problems. Maintenance of airtight seals on boiler openings is difficult. Inspections during shutdown admit moist air. Desiccants, porous chemical drying agents, should be added to the secured boiler to absorb water vapor. Failure to detect caked or spent desiccants during inspection makes the boiler subject to corrosion by humid air. Nonretum valves should be leak-free. This type of dry storage is useful when the plant atmosphere contains corrosive fumes or abrasive dust, that could enter the open, dry boiler. Another dry layup technique consists of completely sealing the drained boiler and maintaining a positive pressure of nitrogen. The nitrogen capping (blanketing) method is discussed under short-term, wet standby procedures. Finally, extended storage of a boiler can be accomplished by maintaining the boiler sealed and drained while under steam pressure. Traps on the mud drum and lowest header remove condensate. Vents for noncondensibles are installed at dead end points in the boiler. Dampers and all openings to the furnace are closed tight. This system has the advantage of keeping the boiler hot, thus preventing condensation and resultant fireside corrosion.

5.5 DEPOSITS IN STEAM GENERATING SYSTEMS.

5.5.1 Preboiler Section. The preboiler section includes all piping and equipment from the point of raw water pickup (river, wells, city water) to the point of entry into the boiler. Preboiler section deposits can form in several locations. Deposits in deaerating heaters interfere with water distribution and deaeration, and in feedwater lines they restrict flow. In economizers and other feedwater heaters, deposits limit heat transfer while promoting corrosion. In feedwater regulators, deposits cause a loss of water level control, producing irregularities in circulation and causing carryover. Preboiler section deposits can be caused by oversaturation of calcium carbonate, reaction between hardness and treatment chemicals, contaminated condensate, or presence of iron.

5.5.2 Deposits Caused by Contaminated Condensate. Contamination of steam and condensate generally originates from one or more of the following sources:

- Leaking coils or jackets.
- Product backup in open coils.
- Corrosion of metals in the afterboiler section.
- Raw water injection into condensate to prevent flashing or for desuperheating.
- Condenser leakage.
- Boiler carryover.
- Interconnection of condensate lines to industrial sewers.

Steam can become contaminated with oil when used in fuel oil heaters or when operating reciprocating pumps, compressors, and engines. Condensate from fuel oil heating is usually discarded. In many instances, baffle type oil separators remove oil from the exhaust steam of equipment such as steam-driven reciprocating pumps. Separators must be checked periodically to ensure against malfunction. Process contamination occurs more frequently in intermittent operations than in continuous ones. Potential for contamination is greater when steam contacts products directly through open lines than in closed piping or jackets; leaks in piping or jackets can result in contamination. Contaminated condensate recovered and returned for use as feedwater can cause contaminants to react with feedwater constituents. Precipitates can form deposits on metal surfaces. The contaminant can bind precipitates, making them more adherent. Condensate contamination, caused by carryover of boiler water, adds sludge caustic, and orthophosphate to the feedwater that, in turn, can result in additional sludge formation. Frequent testing of condensate, either intermittent or continuous, is necessary to detect contamination. Steam and condensate conductivity alarm systems may be adequate for continuous monitoring. Such systems generally consist of a sample cooler, conductivity cell and accompanying holder, controller, and alarm. In some situations, a conductivity cell can be installed directly in a condensate line. When impurities are detected, condensate should be diverted or discarded until the source of contamination has been located and eliminated. Other monitoring methods provide detection of sodium and hardness and measurement of pH, total organic carbon, and turbidity.

5.5.3 Deposition of Corrosion Products. Iron and copper corrosion products in returned condensate can cause preboiler section deposits by direct adherence or by acting as a binder. Condensate should be monitored for metal ion content and corrosivity and for presence of condensate corrosion inhibitors. When inhibitors cannot be used, substitution of condensate filters and polishers is appropriate to remove iron and copper oxides.

5.5.4 Boiler Deposits. The most severe effects of deposits in steam generating systems occur in the boiler. Presence of deposits on heat transfer surfaces disrupts a boiler's basic function. Deposits on the waterside of a boiler result in overheating of tubes and subsequent metal softening, expansion, thinning, and, ultimately, failure. Boiler metal begins to lose strength rapidly as temperature increases above 900°F. Deposit-caused tube failure usually occurs in sections of the boiler where greatest heat transfer takes place. Therefore, riser (generating) tubes are most susceptible. Boiler deposits result in tube failure when the insulating effect of a deposit elevates temperatures to the metal softening point. The type and thickness of a deposit determines the extent of reduced heat transfer. Even in situations where deposits do not cause tube failure, their insulating effect results in energy waste. Disruption of boiler circulation can occur when deposits loosened by thermal shock collect in a tube

bend or when deposits build up on orifices in a forced circulation boiler. Carryover can result from deposit interference with steam separating devices, particularly where deposits build up on chevron or mesh separators. Tube failure, carryover, and other operating problems can make deposit removal necessary.

5.5.5 **Control Programs.** Boiler water treatment programs normally combine. use of various antiscalants; the goal is to keep the boiler free of deposits,. Selection of a treatment program depends on boiler design, operating pressure, makeup water constituents, type of external treatment, and method of operation. Deposit control schemes frequently include a precipitating program. Boiler antiscalants can be divided into two categories: those that chemically react with feedwater impurities to change chemical structure, and those that alter the action of impurities. Commonly used reactants are carbonates, phosphates, and chelants. Antiscalants that alter physical behavior of impurities are select organics, polymers, and threshold-acting sequestrants. In precipitating programs, chemical treatment results in precipitation of boiler sludge instead of scale formation. Phosphate-based programs are precipitating programs.

In phosphate programs, resulting sludge are calcium hydroxyapatite and serpentine. Both are relatively nonadherent and are removed from the boiler with bottom blowdown. Efficient bottom blowdown is essential because sludge can be swept from the bottom of the boiler (where it should settle) into hot sections of the boiler where it can bake on hot tube surfaces. The frequency of bottom blowdown is dictated by the solids load on the boiler and boiler design. One type of solubilizing program employs polymers, metal dispersants, and organic sludge conditioners. These prevent scale formation by distorting crystalline growth of scale and dispersing small particles as colloids. Organics condition the sludge that is formed. This program relies heavily on use of specific metal dispersants to prevent binding of precipitates. The choice of program is often dictated by economics. A chelant program, for example, is usually too expensive if hard makeup water is used and very dangerous if poor control of the chelant feed occurs. Excessive chelants will remove iron from the walls of the boiler and can rapidly perforate the boiler tubes.

5.6 OTHER BOILER DEPOSIT PROBLEMS.

5.6.1 **Contamination.** Contaminants, such as oil and process materials, can be introduced to a boiler through condensate return and can lead to deposit formation. Although process contaminants can occasionally form boiler deposits as a classic scale or sludge, those most commonly encountered cause deposit formation by binding sludge or by charring on heat transfer surfaces. When the contaminant is an oily substance, the problem can be reduced by maintaining high concentrations of hydrate alkalinity and by using an organic dispersant. The best solution is to avoid the problem by external treatment of

condensate to remove contaminants, or by monitoring condensate and discarding it if contaminated.

5.6.2 Boiling Out.   When a boiler contains oily or greasy deposits, a boilout is usually recommended. Such a procedure is also necessary on new boilers that usually contain protective greases to inhibit corrosion prior to use. In addition, dirt, debris, and mill scale must be removed. Boilout is usually accomplished using an alkaline material, such as trisodium phosphate, disodium phosphate, sodium hydroxide, soda ash, or sodium silicate. A separate descaling with hydrochloric or other acid, following degreasing, may be necessary for removal of operational deposits or for boilers with severe mill scale.

5.6.3 Mineral and Metal Deposits.   The inefficiency and potential hazards created by a dirty boiler make cleaning advisable as soon as possible after discovery of deposit buildup. Cleaning may be accomplished onstream or offstream, as conditions warrant. Onstream cleaning is often recommended for low- and medium-pressure boilers that have a high ratio of hardness salts (Ca and Mg) to other deposit constituents and when deposit formation is uneven. One method of onstream cleaning uses high concentrations of chelant, with polymers and organic sludge conditioners. Use of polymers to disturb the already formed deposit and to assist in breaking down deposit structure is important. Organics are helpful in preventing redeposition An onstream cleaning program should be accompanied by heavy bottom blowdown, and is usually designed to take 30 to 90 days. Rapid onstream deposit removal should be avoided to minimize the possibility of redeposition or plugging. The choice of an offstream cleaning program is determined by the nature of deposits to be removed. A relatively mild acid, such as sulfamic acid, can be used to remove deposits containing high concentrations of magnesium or calcium More elaborate cleaning procedures may be needed when significant percentages of metal oxides or silica are present. Chelants or acids are usually used for removal of metal oxides or mineral deposits; fluorides are usually used for silica.

5.6.4 Nonchemical Boiler Deposit Problems.   No guarantee against boiler deposits exist even if a chemical treatment program is well designed and external treatment equipment is operated effectively. Deposits frequently result from mechanical problems that are most often traceable to operating conditions. Overloading, rapid load swings, improper burner alignment, and defects in boiler design can also cause deposition and corrosion.

5.6.5 Overheating.   Local hot spots, or overheating, can be harmful to the boiler. Rapid steam formation at the heat transfer surface (film boiling) is a cause of boiler scale. When film boiling occurs, salts dissolved in the boiler water remain as a deposit. Buildup of baked-on sludge or organics can occur in local hot spots. These deposits cause the area to become more susceptible to

failure from overheating. Rapid corrosion is another problem caused by over-heating. Flame impingement (when the flame actually touches boiler tubes) constitutes a prime cause of local overheating in a boiler. This condition usually arises from misalignment of burners and can be detected by adding a copper salt to combustion air to give the flame a visible blue-green color. Overfiring of the boiler causes hot spots. If the boiler is operated above designed capacity, cir-culation of boiler water may be insufficient to cool heat transfer surfaces. Resul-tant overheating and subsequent failure can occur in areas of poor circulation. All circulation problems are not related to overfiring. Inadequate circulation can develop in floor tubes, roof tubes, or riser tubes adjacent to downcomers. In horizontal tubes, water may not wet the top portion of the tube; in vertical tubes, poor circulation may cause inadequate flushing of heat transfer surfaces. These problems often result from low loading of the boiler or from boiler design flaws. Tube failure resulting from overheating can also be caused by star-vation, a condition where water supplied to an area of a tube in an operating boiler is inadequate. Starvation can result from deposits in the lower bend of a screen tube or in the lower header of a wall tube.

5.6.6 Intermittent Use. Boilers used intermittently are subject to deposit problems. When a boiler is offline, suspended solids settle and deposit on metal surfaces. In time, these deposits harden and bake on when the boiler is brought back online. Deposits can develop during intermittent boiler use even with a water treatment program. Deposits are usually multilayered and can become quite thick.

5.6.7 Removal From Service. There is an advantage to removing sludge before a boiler is taken out of service. This can be accomplished by fre-quent bottom blowdown, for a period of 1 to 3 days, before the boiler is secured. Blowdown should be accompanied by increased dosages of sludge conditioner to keep solids in suspension. Once removed from service, the boiler should not be drained until allowed to cool. Draining a hot boiler can cause suspended solids to bake onto hot metal. After the boiler is drained, it is usually beneficial to rinse with high-pressure water.

5.6.8 Afterboiler Section. The afterboiler section includes a super-heater, turbines, steam distribution system and equipment, and condensate lines. Deposits can form in these areas as a result of carryover, raw water or process contamination, condenser leakage, inadequate return line treatment, and migration of corrosion products. Deposits on turbine blades cause distor-tion of designed velocity and pressure profiles, imbalance, and corrosion. Deposits in the steam system and equipment reduce heat transfer and can cause malfunction of steam traps. For more information on steam traps see MO-209. Poorly functioning steam traps are a major cause of steam loss. Deposits in con-densate lines cause localized corrosion and generate additional deposit-forming

corrosion products. Return line failures represent loss of valuable heat and high quality condensate, and can cause shutdowns. Whenever possible, condensate streams subject to contamination should be diverted to other uses or handled separately and treated. If returned, monitoring of pH, conductivity, or other specific analytical methods is advisable, with provisions for automatic condensate disposal. Composite sampling of various condensate streams can reveal a periodic contamination problem. In summary, afterboiler deposits are usually caused by corrosion and contamination. The best way to prevent afterboiler deposits is to reduce corrosion and contamination.

5.7 PREVENTING CONDENSATE CORROSION. Condensate can be contaminated by evolution of gases from boiler water and by air leakage into the steam-condensate system. The primary source of carbon dioxide in steam condensate systems is carbonate and bicarbonate alkalinity in boiler makeup water. Carbonates and bicarbonates, when subjected to boiler temperatures, degrade to carbon dioxide. Carbon dioxide dissolved in pure water reacts to form weakly ionized carbonic acid. Very little carbon dioxide is needed to sharply reduce pH of water and to substantially increase its corrosivity. In pure condensate at 140°F, only 1 ppm dissolved carbon dioxide will decrease pH from 6.5 to 5.5. In the absence of oxygen, acidic condensate generally causes uniform attack, leaving a rather smooth surface where iron has been dissolved. Dissolved oxygen is significantly more corrosive than carbon dioxide. Oxygen dissolved in pure water at 140°F has been found to be 6 to 10 times more corrosive to iron than molar equivalent concentrations of carbon dioxide. Where both gases are present in solution, the resultant corrosion rate can be 10 to 40 percent greater than the sum of corrosion rates of the two gases acting separately. Two basic approaches to prevent condensate corrosion are as follows:

- Elimination (or minimization) of oxygen and carbon dioxide contamination

- Use of chemical inhibitors to counteract corrosive conditions

5.7.1 Minimization of Oxygen and Carbon Dioxide Contamination. Feedwater dissolved oxygen and carbon dioxide can be eliminated by mechanical deaeration plus use of an oxygen scavenger (catalyzed sodium sulfite or hydrazine). Chemical scavenging alone also is sometimes effective but only in controlling oxygen attack. Even though feedwater oxygen can readily be reduced to zero by such means, it is difficult to completely eliminate air inleakage into steam-condensate lines. Various pretreatment methods can be used for reducing or eliminating makeup water carbonates and bicarbonates (sources of boiler water carbon dioxide). Lime softening gives some alkalinity decrease; special ion exchange processes such as split-stream softening, deakalization, and demineralization, also reduce or remove alkalinity. Even with pretreatment to reduce potential carbon dioxide, chemical inhibitors are usually necessary to complete the process.

5.7.2 Use of Chemical Inhibitors.   Two basic types of chemicals are used to prevent condensate corrosion: neutralizing inhibitors and filming inhibitors. Neutralizing inhibitors are volatile, alkaline chemicals that bind up carbon dioxide gas as a carbonate radical. Thus, they protect against carbon dioxide attack, but do not prevent oxygen corrosion. Filming inhibitors, properly applied, form a barrier between metal and condensate. They prevent both carbon dioxide and oxygen attack by isolating the metal surface of the condensate line from the aggressive atmosphere of these aggressive gases. Use of filming inhibitors is not authorized in Navy-owned systems and special cautions should be observed regarding safe use of amines. The most commonly used neutralizing inhibitors are amines such as morpholine, cyclohexylamine, and diethylaminoethanol (DEAE). The ability of each product mentioned to enter the condensate or water phase is indicated by its vapor-to-liquid distribution ratio. This ratio compares concentration of amine in the vapor phase to concentration in the water phase.

Product	Vapor-to-Liquid Distribution Ratio
Morpholine	0.4 to 1
Cyclohexylamine	4.0 to 1
Diethylaminoethanol	1.7 to 1

To neutralize carbonic acid, amine should be present in the water phase. The distribution ratio signifies which amines prefer the water phase and which prefer the steam phase. An amine such as morpholine, that has an affinity to the water phase, will be present in initially formed condensate where the percentage of steam is high compared to condensate. On the other hand, cyclohexylamine tends to remain with the steam and enter the condensate as temperature decreases and the percentage of steam in relation to condensate decreases. This causes morpholine to condense and protect the condensate lines near a boiler plant and cyclohexylamine to delay condensing until it reaches the condensate lines distant from the plant. Because of their differing vapor-to-liquid distribution ratios, two or more such amines can be used together to provide highly effective neutralization programs for complex systems. Neutralizing amines are fed to either the feedwater, boiler, or steam header but never before the deaerator. Their effectiveness is monitored by analysis of returned condensate pH from samples taken at the beginning, middle, and end of a condensate system. Neutralizing amines are partially regenerated in the deaerator as the carbonate is released in the form of carbon dioxide and the amines again pass into the boiler along with the boiler feedwater.

Safe Usage of Amines. Special caution should be observed when using live steam in humidification systems. Problems have been experienced with additives such as morpholine and DEAE. Special care should be observed where

steam comes into direct contact with food or is employed as a sterilization agent for hospital equipment.

5.8 HIGH TEMPERATURE HOT WATER. High temperature hot water (HTHW) heaters are commonly used for space heating and process purposes. Water heaters are similar to boilers in appearance, except that water is kept under pressure to prevent boiling. For an expanded discussion of High Temperature Water Distribution Systems refer to Appendix D and NAVFAC MO-209. Normally, HTHW systems are closed loop systems. Impurities enter the system in makeup water. (See Appendix D for treatment). The following points should be observed for HTHW systems:

- Eliminate leakage wherever possible or redesign piping circuit.

- Deaerate the make-up water and use an oxygen scavenger such as sodium sulfite in initial fill and periodically to reduce oxygen corrosion.

- Fill system with water treated by a sodium zeolite anion dealkalizer, or use conditioned condensate or demineralized water.

- Provide an initial treatment to coat and protect metal surfaces.

- Periodically provide treatment to fluidize precipitated solids. Precipitated solids should be periodically removed. Rate of removal depends on rate of makeup water used.

- Expansion tanks should be bladder or piston type so air does not contact water. If expansion tanks are other than bladder or piston type, the tank volume above the water should be charged with nitrogen.

5.9 TYPES OF COOLING WATER SYSTEMS. Three types of cooling water systems are used:

- Once-through systems.

- Closed, recirculating systems.

- Open, recirculating systems.

    5.9.1 Pretreatment. Pretreatment of cooling water systems is necessary to ensure maximum service life of heat exchange equipment. Pretreatment consists of precleaning and prefilming.

Precleaning. Precleaning removes accumulations of foreign material that can reduce heat transfer, restrict flow, and impair corrosion protection. This procedure prepares surfaces of cooling water systems for the prefilming phase of the pretreatment program. Precleaning the entire system, or individual components, should be conducted just prior to startup. Immediately after preclean-

ing, surfaces should be passivated to avoid initial high corrosion rates. Special precautions should be taken with new cooling towers that typically are built of wood pretreated with a copper-based salt. It is imperative to flush new towers to leach out these compounds.

Prefilming. Prefilming is a procedure that promotes rapid formation of an inhibiting film over surfaces of the entire cooling water system or critical exchanger, depending on the method of application. Economics, discharge limitations, and time requirements dictate whether prefilming is applied to the entire system or to individual heat exchangers. Prefilming minimizes initial corrosion that occurs at startup and allows for the most efficient application during a continuing corrosion inhibitor program. The function of prefilming is to permit rapid formation of a uniform, impervious film to immediately stifle the corrosion reaction. When this film is established, continuous low treatment levels will maintain the film intact and will avoid accumulation of corrosion products. The continuous low treatment level heals slight breaks that can occur from minor variations in environment. Whenever any serious changes in environment occur that cause destruction of the film, corrosion products can accumulate before the film is reestablished by treatment. Under these conditions, normal control should be restored and a prefilming program should be conducted to passivate the system. Prefilming of equipment in cooling water systems is recommended for the following:

- New heat exchange equipment.
- When equipment is acid-cleaned.
- When low pH conditions occur.
- When serious process leakage occurs.
- Immediately following startup after turnarounds or inspections.

Application of principles of pretreatment for rapid film formation, followed by use of normal treatment levels for film maintenance, will prove beneficial in minimizing corrosion. In general, improved heat transfer, longer service life, and less plant maintenance will be realized.

    5.9.2 Once-Through-Systems. Once-through systems use cooling water once before discharging to waste. Even small once-through cooling systems use relatively large amounts of water. Thus, these systems are generally employed only where water is available at a suitably low temperature, in large volume, and at low cost. The usual sources of once-through cooling water are wells, rivers, and lakes, where the only cost involved is for pumping. Generally, the only external treatment applied to once-through water taken from rivers and

lakes is rough screening to remove objects that can damage pumps and heat exchange equipment and chlorination to control biological foulants. Because evaporation is negligible in these systems, mineral characteristics of both influent and effluent water are virtually the same.

Scale Formation. Scale deposits formed in cooling water lines and heat exchange equipment may be of several types: precipitated calcium carbonate; accumulated corrosion products; and mud, silt, and other debris. It is important to recognize the mechanism of formation for these deposits and corrective methods required to prevent them. Temperature, heat transfer rate, calcium, sulfate, magnesium, silica, alkalinity, dissolved solids, and pH are factors affecting scale formation. Calcium carbonate is a chief component of scale found in many once-through cooling water systems.

Calcium Carbonate Scale. Softening raw water for use in once-through systems is not usually economical because of large volumes of water used. If a softening plant exists to supply water for other plant purposes, it may be practical to use the facility to soften reasonable volumes of once-through cooling water. The usual method of inhibiting calcium carbonate scale is use of deposit control agents. These agents inhibit scale at an acceptable cost. The deposit control agent used should prevent crystal growth and scale formation by permitting scale-forming salts to exist in a supersaturated condition without precipitation. Commonly used agents are polyphosphates, polyacrylates, and organic phosphonates. Blending of agents can combine advantages of each to solve a particular problem.

Iron Deposits. Once-through systems using iron-rich well water, may experience scale formation caused by oxidation of ferrous iron as water comes into contact with oxygen. In such instances, either sequestrants or dispersants that are specific in activity on ferrous and ferric ions, can prevent precipitation. Agents such as polyphosphates, organic phosphonates, and polyelectrolytes are suitable for treating this problem. Iron deposits can occur in systems that use iron-containing river water. Iron, in the form of ferric hydroxide, may initially deposit on piping and heat exchange surfaces of a once-through cooling system. Oxygen from cooling water will tend to oxidize a portion of this deposit to ferric oxide, resulting in a deposit rich in iron oxide and silt. Figure 5-5 shows a graph of the relationship between deposits and system efficiency. Treatments using combinations of organic phosphonates, polyacrylates, and selected surface-active agents are successful in removing deposits containing high amounts of iron and silica and in preventing further deposits from forming. Normally, for economic reasons, treatment chemical is fed intermittently. Quality of water and analyses of deposits in a system dictate frequency and concentration of the intermittent feed. Iron deposits also result from corrosion. This can be caused by general corrosion of piping in the cooling water system or by galvanic corrosion where
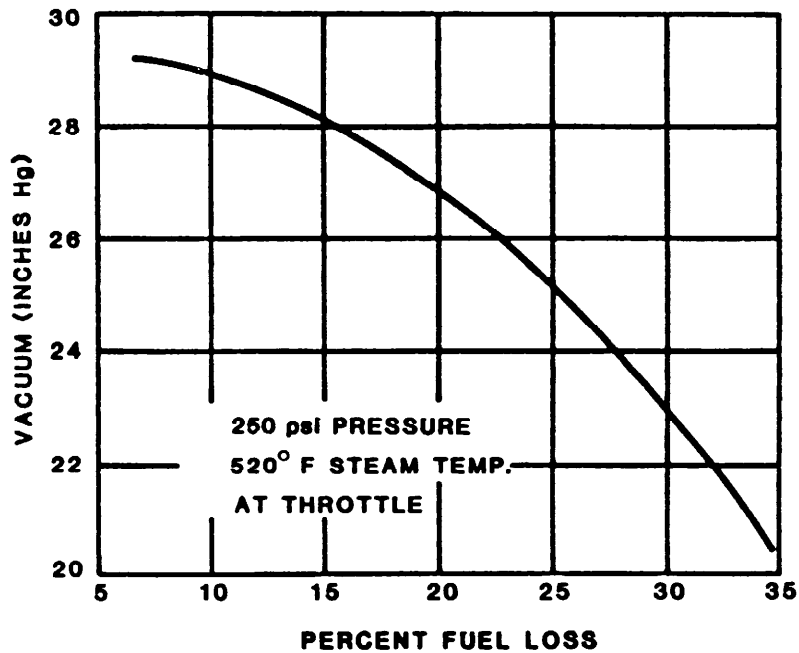
FIGURE 5-5
Fuel Efficiency Loss Resulting From Condenser Deposits
(Courtesy Drew Chemical Company

two dissimilar metals join.

General Fouling. In addition to iron deposits, general fouling from mud, silt, and organic debris can be a problem with river water makeup. This is especially true during periods of upset conditions such as rainy weather and high runoff. To protect critical cooling systems from general fouling, surface-active deposit control agents are used, with combinations of polyacrylates and biocides fed intermittently. By modifying surface characteristics of contaminants, these materials decrease both tendency of particles to settle out of water in low flow areas and to stick to surfaces of piping and critical cooling surfaces.

Corrosion Control. Corrosion is defined as destruction of metal by chemical or electrochemical reaction with its environment. In cooling water systems, metal destruction can cause several serious problems. Unchecked, it can lead to expensive replacement of equipment and production losses from unscheduled downtime. An accumulation of corrosion products reduces capacity of piping and increases frictional resistance and pumping costs. Red water, caused by corrosion products, is unsightly and interferes with iron sensitive processes.

5.10 CLOSED, RECIRCULATING SYSTEMS. Removing heat from stationary engines and compressors requires attention by plant operating personnel and water treatment consultants. In a closed, recirculating system (Figure 5-6), water circulates in a closed cycle subjected to alternating cooling and heating without air contact. Heat, absorbed by water in a closed system, normally is transferred by a water-to-water heat exchanger then to the atmosphere or to some other heat sink. Closed, recirculating systems are suited to cooling engines and compressors. Diesel engines, in stationary and locomotive service, normally use: radiator systems. Closed systems are also used in chilled water systems of air conditioners to transfer refrigerant cooling to air washer units where the air is chilled. The same system, in winter operation, can supply heat to air washers. Industrial process temperature control is another area suited to a closed system.

FIGURE 5-6
Typical Closed Cooling System

     5.10.1 Advantages of Closed Systems. Closed, recirculating systems provide better control of cooling water temperatures through heat-producing equipment; smaller makeup water requirements greatly simplify control of water caused problems. Makeup water is needed only to replace losses from

leakage at pump packings or when the system is drained for repairs. Little, if any, evaporation occurs. By minimizing scale problems, these systems practically eliminate dangers such as cracked cylinders and broken hea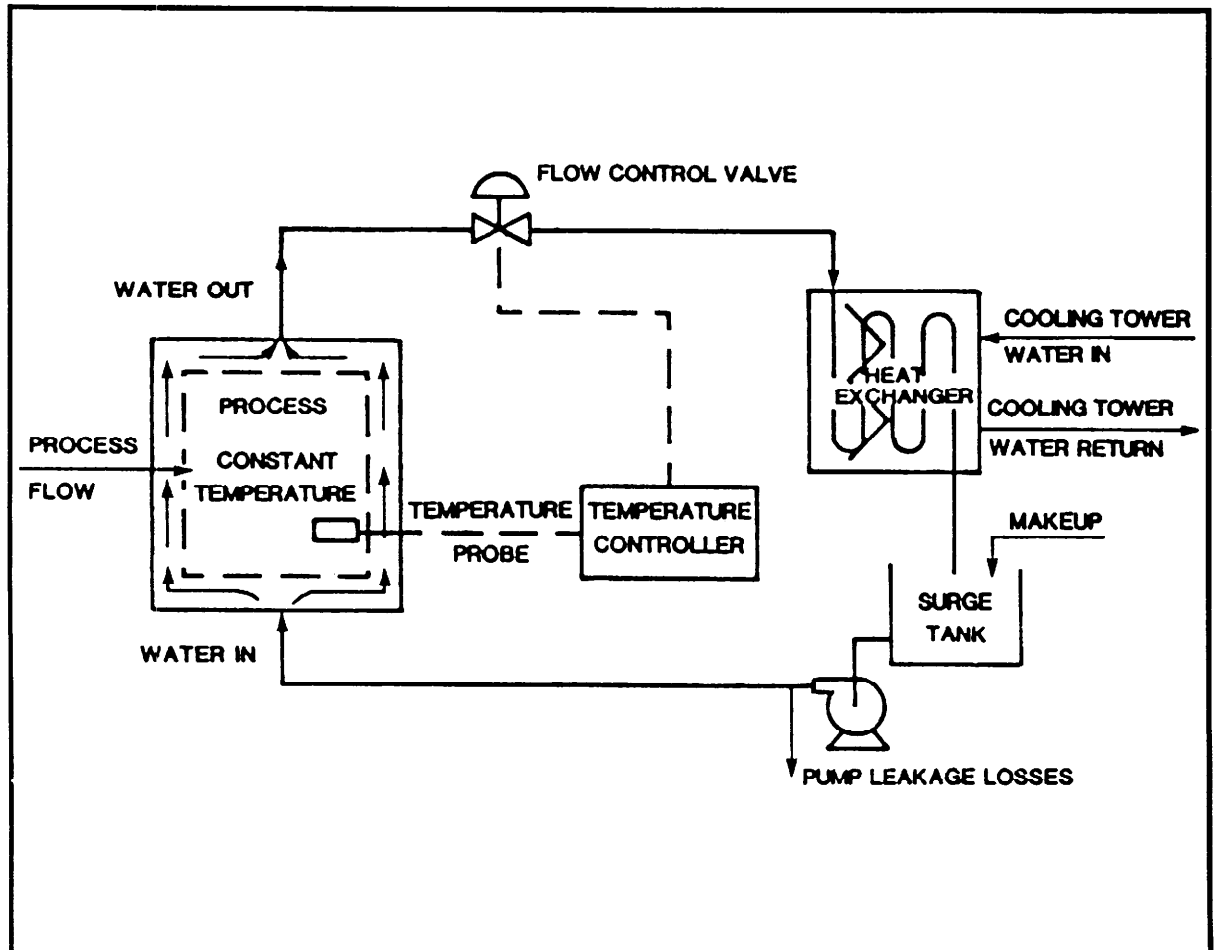ds. Moreover, closed systems are less susceptible to biological fouling by slime and algae that result in scale deposits. Closed systems reduce corrosion problems because recirculating water is not continuously saturated with oxygen, as in an open system. The only possible points of oxygen entry are at the surface of the surge tank or hot well. With the small amount of makeup water required, treatment can virtually eliminate corrosion and accumulation of corrosion products.

5.10.2 Scale Control. Closed systems that operate at relatively low temperatures require very little makeup water, and since no concentration of dissolved solids occurs, fairly hard makeup water can be used with little danger of scale formation. In diesel and gas engines, however, high temperature of jacket water increases tendency to deposit scale. Over long periods, additions of even small amounts of hard makeup water will cause a gradual buildup of scale in cylinders and cylinder heads. Where condensate is available, it is preferred as cooling water makeup. Where it is not available, softened makeup water should be used.

5.10.3 Corrosion Control. Untreated systems can suffer serious corrosion from oxygen pitting, galvanic action, and crevice attack. Closed cooling systems that frequently shut down will have water temperatures vary from 185°F to ambient. During shutdown periods, oxygen can enter water until its saturation limit is reached. Oxygen solubility drops when the system is returned to higher temperature operation, allowing excess undissolved oxygen to attack metal surfaces. Materials used in engines, compressors, and cooling systems include cast iron, steel, copper, copper alloys, aluminum, and zinc and tin alloy solders. Nonmetallic components such as natural or synthetic rubber, asbestos, and carbon are also used. If bimetallic couples occur, galvanic corrosion can develop. The three most reliable corrosion inhibitors for closed cooling water systems are chromate-, silicate-, and nitrite-based compounds. Chromate-based treatments are generally superior, but are often prohibited because of environmental considerations. The most common closed loop corrosion control program consists of the addition of sodium nitrite, sodium borate and a small percentage of sodium mercaptobenzothiazole.

5.11 OPEN, RECIRCULATING SYSTEMS. Industry is turning increasingly to recirculating systems. An open, recirculating system with a cooling tower, spray pond, or #evaporative condenser to dissipate heat, permits reuse of water and reduces the amount of makeup water needed. However, such a system intensifies potential for scaling, fouling, and corrosion.

5.12 DEPOSIT CONTROL. Selection of a deposit control program should be governed by an appraisal of interrelated factors that constitute the deposit problem. Ensuring adequate control over blowdown rate can sometimes control deposits. Other situations require a sophisticated program that may involve at least two chemical deposit control agents and mechanical modifications, such as installation of a side stream filter. Deposit problems vary from tenacious films that are barely visible, to complete blockage of heat exchanger tubes. They can usually be categorized as scaling or general fouling.

  5.12.1 Scale Formation. Scaling is precipitation of dense adherent material on heat exchange surfaces. Precipitation of scale-forming salts occurs when solubilities are exceeded because of high concentration or increased temperature. Solubilities of most scale-forming salts in cooling water decrease with increasing temperature. Passing circulating water through heat exchange equipment increases water temperature. This rise in temperature is frequently sufficient to cause precipitation of scaling material on heat transfer surfaces. The 'concentrating mechanism in open, recirculating systems is also the cooling mechanism, that is, evaporation of water when it passes through a spray pond or tower. As pure water is evaporated, minerals in circulating water remain behind., resulting in water that is more concentrated than makeup water. The term that compares concentration in circulating water to makeup water is cycles of concentration. For example, circulating water that has twice the mineral concentration of makeup water has two cycles of concentration. Windage (drift loss), fine droplets of water entrained in circulating air, and tower carryover limit the degree of concentration. Makeup water should replace both windage and evaporation losses.

Windage losses vary with the type of open, recirculating system, but the following may be considered typical:

Spray ponds	1.0 to 5.0 percent
Atmospheric towers	0.3 to 1.0 percent
Mechanical draft towers	0.1 to 0.3 percent

Calcium carbonate scale is a potential problem in recirculating systems as it is in once.-through systems. In addition, scales of calcium silicate, magnesium silicate, and calcium sulfate must be dealt with in recirculating systems. When makeup water with concentrations shown in Table 5-2 is cycled two times, the circulating water remains non-scale-- forming. When the same makeup water is cycled three times, scaling conditions are indicated. By limiting circulating water cycles and adding acid, scale formation can be prevented. Another method to prevent scale is by keeping the water in an equilibrium alkaline condition and by addition of organo-phosphate sequestering agents.

TABLE 5-2

Circulating Water Analyses

Constituent	Makeup	Circulating Water at Two Cycles	Circulating Water at Three Cycles
Total hardness as $CaCO_3$	60	120	180
calcium as $CaCO_3$	50	100	150
Magnesium as $CaCO_3$	10	20	30
P alkalinity as $CaCO_3$	0	0	10
M alkalinity as $CaCO_3$	50	100	150
Sulfate as SO_4	40	80	120
Chloride as Cl	10	20	30
Silica as SiO_2	5	10	15
	Above values expressed in ppm		
pH	7.0	7.3	8.3
pHs (140°F)	7.8	7.3	6.8
Saturation index (Lang.)	- 0.8	0.0	+1.5
Stability index (Ryznar)	8.6	7.3	5.3
Interpretation	Non-scale forming	Non-scale-forming	Scale forming

Control of Cycles. Limiting cycles of concentration is a principal means of eliminating scale formation. By limiting mineral concentration in circulating water, oversaturation can be prevented or held within the effective range of treatment used. Natural windage loss may limit cycles of concentration sufficiently. Where it does not, windage loss should be supplemented with blowdown. Blowdown removes a portion of the concentrated circulating water, which is then replaced with fresh makeup water. This lowers mineral concentration in the system. Both continuous and intermittent blowdown are used; however, continuous blowdown is preferred. While blowdown is an effective way to limit both cycles of concentration and scaling potential of circulating water, excessive rates of blowdown may not be tolerable. Depending on water quality, blowdown cannot always accomplish scale control. In many localities, supplies of fresh water are limited or costly. Rather than increase blowdown, acid addition can be used to prevent scale formation, thus permitting higher cycles of concentration.

Acid Treatment. Sulfuric acid is commonly used to treat circulating water. Sufficient acid should be used to reduce, but not to eliminate, circulating water alkalinity. Alkalinity is reduced to achieve saturation and stability indices that

indicate nonscaling conditions. When acid is used, feeding equipment should be as automatic as possible to minimize adjustment by operating personnel. In most cases, investment in automatic pH control of acid feed is mandatory. The consequences of severe pH drop excursions due to uncontrolled sulfuric acid addition can be catastrophic in a very brief time of exposure.

Side Stream Filtration. This process is applied to the recirculating water to remove some of the total suspended solids using mechanical filters. A valveless, side-stream filter, using gravity flow, passes up to five percent of the water through a sand (most common) or anthracite filter at about three gallons per minute per square foot. Usually side stream filters are used on cooling towers where there is an accumulation of dirt and debris. These filters are impractical when oil is the contaminant because of rapid fouling of the filter media. Where a need exists to increase the number of cycles of concentration in the tower, cold lime softening may be added with the advantages of removing suspended solids and reducing hardness. Blowdown from softening goes to waste after sludge thickening and dewatering. If the tower system has zero bleedoff, softener blowdown goes to an evaporator or pond.

5.12.2 Fouling. Fouling of heat exchanger tubes is usually defined as deposition of non-scale-forming materials such as:

- Silt or iron suspended in makeup water.
- Naturally occurring organics in makeup water.
- Particulate matter scrubbed from the atmosphere.
- Deposition of chemical additives due to poor control.
- Organic contamination from process leaks.
- Migrating corrosion products.

Control of Fouling. Treatment with dispersants is economical for a wide variety of fouling substances. Low molecular weight polymers are effective dispersants in industrial cooling water systems. Another approach to controlling deposition is to apply high molecular weight polymers (flocculants) that promote formation of a light, fluffy floc. Floc is removed through blowdown and/or side-stream filters. One hazard of using this approach is subsidence in low flow equipment, such as in the shell side of heat exchangers. Onstream desludging is generally designed for temporary relief from fouling. An onstream desludging program should be tailored to suit individual chemical and mechanical requirements of a particular system. A typical program is conducted over 120 consecutive hours with the dispersant at the recommended increased dosage and blowdown increased to lower cycles of concentration. At the conclusion of a cleaning program, a high concentration of continuous corrosion inhibitor or a prefilming agent is introduced to passivate the system. Fouling

trends can be followed by plotting heat transfer rates versus time. Heat transfer coefficients may be calculated manually or determined instantaneously with an electronic instrument that integrates temperature and flow measurements. The degree of fouling can be closely monitored with test heat exchangers and deposition testers. Deposition testers are also used to obtain an assessment of the deposit potential of water.

5.13 CORROSION. Preventing corrosion in open, recirculating water systems has received much research attention. Effective anticorrosion measures have been developed that can be applied at reasonable cost. The expense of corrosion prevention is minor when compared to the cost of downtime, production losses, and equipment replacement. Corrosion damage can require complete replacement of heat exchangers, pumps, and lines.

5.13.1 Causes of Corrosion.   Because of the nature of recirculating systems, corrosion problems are intensified. Contact of cooling water with air creates unique corrosion problems. Continual replenishment of oxygen in cooling water, as it passes over a cooling tower or through a spray pond, is the primary cause of corrosion in open, recirculating systems. Airborne contaminants such as gases (sulfur dioxide, ammonia, hydrogen sulfide) and particulate matter (sand, dust, dirt, fly ash) scrubbed from the air by cooling water, increase corrosion rates.

5.13.2 Prevention of Corrosion.   Control of corrosion in open, recirculating systems is primarily achieved by maintaining small quantities of chemical additives (corrosion inhibitors) in the cooling water. Corrosion inhibitors most frequently used in cooling water systems are classified as passivators. These inhibitors passivate metal by encouraging an oxide, or other film, to form on metal surfaces. Combinations of chromate, polyphosphates, and zinc are the most commonly used inhibitors. Chromate-based systems are often prohibited for environmental considerations. Other corrosion inhibitors include nitrites, silicates, amines, and various organic agents. Control of operating parameters such as inhibitor levels, pH, and dissolved solids in recirculating water is essential to achieve consistent corrosion inhibition. Control is vital when non-chromate treatment programs are utilized.

Use of automatic control equipment greatly increases reliability of any corrosion inhibitor program.

5.13.3 Corrosion of Nonferrous Metals.   Copper and its alloys are frequently used in cooling water heat exchangers. Copper alloys are relatively resistant to corrosion, but specific chemical and mechanical factors permit cor-

rosive attack. Among the more common types of attack are dezincification, impingement, erosion/corrosion, stress cracking, and fatigue cracking. Because many copper alloys are available, an ahoy should be selected that meets requirements of the particular service condition. Some chemical factors that contribute to corrosion of copper alloys are low pH, ammonia, cyanide, sulfide, and excessive chlorine residuals. When attack occurs, the copper content of circulating water generally increases and can adversely affect steel metallurgy in the system Copper can deposit on steel and create cell action that will seriously pit the steel. Both chromate and nonchromate programs provide protection for copper and copper alloys.

5.13.4 Monitoring and Control. Cooling water systems should have a means of monitoring corrosion. This can be a corrosion coupon bypass or a continuous corrosion monitor. A test heat exchanger should also be available to ascertain fouling characteristics and corrosion rates in the system under conditions that simulate large plant operations. Data obtained from a monitoring device can help determine refinements to an inhibitor treatment program.

5.14 MICIRBIOLOGICAL CONTROL. Control of biological fouling is necessary to avoid heat transfer losses and to minimize corrosion induced by slime and algal growths. Both once-through and open, recirculating water systems are susceptible to fouling, but generally the problem is more severe in recirculating systems. Exposure of circulating water to sunlight in cooling towers and spray ponds encourages algae growth. Ideal water temperatures, higher concentrations of nutrients, and greater incidence of airborne contamination increase the slime-forming potential in open, recirculating systems.

5.14.1 Difficulties Due to Biological Fouling. Biological fouling, in open, recirculating cooling systems, is the result of excessive growth and development of algae, fungi, and bacteria. In general, the principal difference between algae and fungi is algae manufacture self-nutrients. Except for a few autotrophic types, bacteria do not manufacture food. Because sunlight is necessary for growth and development of algae, abundant algae growth if not controlled, occurs in spray ponds and in exposed parts of cooling towers. The principal types of biological growth that occur in nonexposed portions of cooling systems are referred to as slime. Slime is an accumulation of micro-organisms and their excretions together with imbedded debris. Micro-organisms usually found in slime deposits are various bacteria, filamentous fungi, yeast, and occasionally protozoa. Slime growths also contain dead algae that have become entrapped in the mass. Slime growths can occur in either illuminated or dark areas. Slime deposits on process equipment retard heat transfer creating a serious loss in efficiency. Biological fouling on metal surfaces creates differential oxygen concentration cells and results in serious pitting.

5.14.2 <u>Choice of Biological Control Programs.</u>   Biological growth control materials in use are biocides and biostats. Biocides kill organisms; biostats inhibit growth and reproduction. Whether a biocidal or biostatic agent is used, a residual concentration must be maintained for sufficient contact time for the agent to function. For biostats to be effective, the residual should be maintained continuously. Economics normally dictate intermittent treatment in cooling systems. Treatment periods vary from 15 minutes to as much as 4 hours. The object is to achieve an effective level of available residual at the system effluent. Dosages and contact times needed to accomplish this are determined by experience. Intermittent, or shock treatment, allows organisms to multiply for a time; subsequent treatment removes them from system surfaces. The period needed for growth and removal varies in every system, even where the water source is the same. Many variables influence the biological development process. Each system should be considered individually, and programs should be varied for seasons of the year. Selection of a treatment program requires definition of the existing or anticipated problem Deposits should be analyzed in the lab- oratory, source determined, rate of formation established, and importance of elimination considered. Laboratory heat exchangers for testing and test coupons (panels) are valuable because they can be used for evaluation without interrupting system operation. System inspection provides the best information on degree of fouling. Cost is the primary criterion in selecting a treatment program. Some factors that affect cost are: chemicals, equipment used to apply chemicals, labor to administer the program, possible deleterious effects on the system, and possible final effluent composition, which may require a permit for discharge. Other considerations affecting a treatment program are safety and handling.

5.14.3 <u>Oxidizing Biocides.</u>   Toxicants used for biological control normally fall into two groups: oxidizing and nonoxidizing biocides. In addition to their disinfecting action, oxidizing biocides oxidize other compounds. Chlorine (an oxidizing agent) has a low cost, is toxic to most micro-organisms, and reacts quickly even in low concentrations. The amount of chlorine required to control biological fouling in a system is governed by the following factors:

- Quality of makeup water.

- Amount and type of contact with the atmosphere.

- Nature and quantity of system contamination from such sources as process leaks.

- Other treatment programs.

- Type and amount of biological contamination.

Chlorine is available as a liquid or a compressed gas, and in such neutralized forms as sodium hypochlorite solution, dry calcium hypochlorite, and organic compounds called chlorine donors. The feeding method, whether continuous or intermittent, and the residual chlorine required to control the problem are individual to a specific system and vary from tower to tower in the same plant. To control slime and algae in once-through or open, recirculating systems, sufficient chlorine should be fed to secure and maintain a killing residual in the treated water. A residual should also be maintained in the system long enough to control micro-organisms. Residual chlorine is the total amount of free and combined chlorine remaining in water after chlorine demand has been satisfied. The difference between dosage and residual is chlorine demand. While continuous chlorination is the most effective method of control, it is also the most expensive. Advantages and disadvantages of four chlorination programs are as follows:

Program	Remarks
Continuous chlorination, free residual	Most effective. Most costly. Not always technically or economically feasible due to high chlorine demand.
Continuous chlorination, combined residual	Less effective. Less costly. Inadequate for severe problems.
Intermittent chlorination, free residual	Usually effective. Less costly than continuous chlorination.
Intermittent chlorination, combined residual	Least effective. Least costly.

5.14.4 Nonoxidizing Biocides. Chlorinated phenols are nonoxidizing biocides widely used in recirculating cooling water systems. These biocides are sodium salts of trichlorophenol and pentachlorophenol. Sodium pentachlorophenate, alone or combined in commercial formulations with sodium trichlorophenate, is probably the most widely used chlorinated phenol. Sodium pentachlorophenate is a soluble, stable compound that does not react with most inorganic or organic chemicals that may contaminate a cooling water system With chlorinated phenols, there are many feeding programs that can be employed, ranging from continuous maintenance of a high concentration in circulating water to intermittent addition of material in low concentration at infre-

quent intervals. As with chlorination, a slime control program should be fitted to individual system conditions. It is desirable, from an economic standpoint, to employ intermittent feeding if the problem can be controlled by this method. Unless the system has an unusually low retention time, there should be no marked difference in the inhibitory concentration required with continuous versus intermittent feed.

5.14.5 Evaluating Treatment Programs.

Methods should be established to evaluate biological treatment programs. These include system inspections, chemical and microbiological examinations of the cooling water, variations in operating data, and effect on other treatment programs. System inspections are usually limited to observations of open conduits or cooling towers. Units or portions of systems should be inspected whenever possible. Evaluations can be made using a test heat exchanger that simulates equipment conditions. Corrosion test coupon racks, although valuable, do not include the effect of heat transfer. Examining cooling water for total bacteria population is a common method for evaluating effectiveness of biocides. Population counts indicate what has occurred in the bulk water; they may not indicate the extent of biological growth on system surfaces. Other treatment programs affected by a microbiological control program include corrosion and deposition control.

5.15 COOLING TOWER WOOD DETERIORATION.

Wood is widely used in cooling tower construction. Wood deterioration often shortens the life of cooling towers from an anticipated 20 to 25 years, to 10 years or less. Repair and replacement costs may be excessive and cooling tower operation inefficient. Cooling tower wood can experience three types of deterioration: chemical, biological, and physical. Rarely is one type present without the others; all three types usually occur simultaneously. When deterioration occurs, it is sometimes difficult to determine the type of attack responsible. Physical and chemical deterioration that are more visible render wood more susceptible to biological attack

5.15.1 Chemical Attack.

Chemical deterioration of cooling tower wood commonly becomes evident in the form of delignification or cellulose destruction, resulting in loss of strength. Chemicals that cause delignification are oxidizing agents and alkaline materials. Attack is particularly severe when high chlorine residuals and high alkalinity concentrations occur simultaneously. Wood that has suffered chemical attack has a white or bleached appearance and its surface is fibrillated (resembles a mass of small threads or fibers). Attack is restricted to wood surfaces and does not impair strength of unaffected areas. Wherever cascading water has a chance to wash away surface fibers, a severe thinning of the wood will occur. In serious cases, fibers plug screens and tubes and serve as focal points for corrosion. Chemical attack occurs most frequently

in the fill section and wetted portions of cooling towers where water contact is continuous. It will also occur where alternately wet and dry conditions develop, such as on air intake louvers and other exterior surfaces, and in warm, moist areas of the tower plenum chamber.

5.15.2 Biological Attack. Biological attack of cooling tower wood is of two basic forms: soft, or surface, rot and internal decay. Organisms that attack cooling tower wood consume cellulose. Characteristically, attacked wood becomes dark, loses much of its strength, and also can become brash, soft, punky, cross--checked, or fibrillated. Internal decay, normally restricted to the plenum area, cell partitions, access doors, drift eliminators, decks, fan housings, and supports, is more severe. It is characterized externally by an apparently sound piece of wood that, upon breaking, shows severe internal decay. Because decay is internal, it is difficult to detect in early stages.

5.15.3 Physical and Other Factors. One major physical factor affecting wood is temperature. High temperature affects wood adversely. Continuous exposure to high temperature produces gross changes in anatomical structure and accelerates loss of wood substance: These effects weaken the wood and predispose it to biological attack, particularly in tower plenum areas. Other factors also influence deterioration of tower wood. Areas adjacent to iron nails and iron hardware usually deteriorate at an accelerated rate. These areas lose much of their strength and develop patches of wood that crumble easily. Slime and algal growth and deposition of dust and oil can aid growth and development of soft rot organisms.

5.15.4 Control of Wood Deterioration. The only effective method to protect operating cooling towers is a preventive maintenance program. Preventive measures are relatively easy to accomplish for flooded sections of the tower where chemical and biological attack is limited to wood surfaces. Preventive measures for the nonflooded portions of the tower, where internal decay is the primary concern, are more difficult. The success of a program depends largely on adopting appropriate measures before contamination becomes serious. Controlling chemical and biological surface attack of cooling tower wood in flooded portions of the tower is a water treatment problem It requires use of nonoxidizing biocides to control slime and to prevent biological surface attack, and application and control to minimize chemical attack where chlorine is used. Experience shows that where nonoxidizing biocides alone are used to control slime in tower systems, surface attack is minimal. In many cases, it is possible to use a variety of treatment programs that combine use of chlorine and a nonoxidizing biocide. Where a combination program is possible, chemical attack can be held to a minimum and biological attack can be controlled effectively. Preventive maintenance programs for nonflooded and tower plenum areas require thorough periodic inspections, replacement of damaged wood, and peri-

odic spraying of plenum areas with fungicides. Cooling towers should be inspected thoroughly at least once per year as part of a preventive maintenance program. On the basis of effectiveness in fighting internal decay, seven wood preservation treatments (applied under pressure prior to sale) are rated in the following order of effectiveness:

- Creosote.

- Ammonia-copper-arsenite.

- Acid copper chromate and copper naphthenate.

- Chromated copper arsenate.

- Pentachlorophenol.

- Fluoride chromate arsenate phenol.

- Chlorinated paraffin.

Periodic spraying with an effective fungicide is an essential step in a preventive maintenance program. Plenum areas should be sprayed with fungicide to render the wood resistant to growth and spread of fungi. The object is to apply fungicide at a high enough concentration so the wood remains fungistatic until the next inspection and spraying.

5.15.5 Wood Examination.   Since several types of wood deterioration occur in cooling towers, physical inspections and laboratory examinations of wood samples should be scheduled regularly. Service laboratories should be equipped with specialized equipment needed to evaluate the condition of the tower wood,. Macroscopic examination of the wood will reveal the degree of grooving erosion and depth of surface attack. Macroscopic study will also reveal the surface structure of the wood, whether chemical or biological decay is present or incipient and, if so, to what extent.

5.15.6 Chlorine.   Chlorine has been discussed at some length because, until recently, it has been the most common effective treatment. However, current limitations on chlorine concentration have led to development of alternative methods of treatment that are more effective, less expensive, and less offensive. These compounds include the following:

- Bromine Chloride. Bromine chloride has a faster decay rate than chlorine and is more expensive, but is significantly more effective. Its major advantage is there is almost no residual toxicity in treated water.

- Chlorine Dioxide. Chlorine dioxide is produced by a simple generator at the point of use. Comments regarding bromine chloride apply equally to chlorine dioxide.

5.16 SAFE USE OF CHEMICALS

5.16.1 Safety Methods. Concentrated chemicals used for plant water treatment should all be considered toxic, and breathing of vapors or dusts should be avoided. Personnel working with chlorine, acid, caustic, and other concentrated chemical feed systems should be trained and should wear rubber gloves, a rubber apron or suit, and a face shield. Respirators, a quick-acting safety shower, eyewash protected against freezing, should be available. **Material Safety Data Sheets (MSDS)** are available from the specific chemical manufacturer and provide detailed information for safe handling and use of sulfuric acid and strong caustic. MSDS information is available from the activity supply department or Safety Office on microfiche, paper copy or CD-ROM through the **Hazardous Materials Information System (HMIS). The Hazard Communication Standard** (29CFR1200) requires that MSDS be maintained in the workplace.

5.16.2 Sulfuric Acid. Concentrated sulfuric acid attacks steel very gradually. As a result, hydrogen, a highly flammable gas, can be generated inside steel storage tanks or piping and can form explosive mixtures with air. Open lights, flames, and spark-producing tools should not be permitted nearby. Level-sensing probes operating on electrical conductivity should be intrinsically safe. Steel or iron pipe should never be valved off at more than one point because generated hydrogen gas can develop dangerous pressures in a completely closed line or result in a blowoff when a valve is opened. Stainless steel or PVC piping preclude hydrogen generation. Sulfuric acid is particularly damaging to organic materials such as cloth.

WARNING
If dilution of an acid is necessary, always add acid to water.
NEVER ADD WATER TO ACID.

5.16.3 Hydrazine. Hydrazine can be absorbed into the body in toxic amounts through vapor inhalation. Furthermore, hydrazine is classified as a carcinogen by the **Occupational Safety and Health Administration (OSHA)** and the **National Institute of Occupational Safety and Health (NIOSH).** Standards for allowable personnel exposure to hydrazine and its salts have been recommended at 0.1 ppm by OSHA, at 0.03 ppm by NIOSH and FDA is zero. Exposure to hydrazine vapor can be limited to acceptable levels through closed feed systems, but potential risks remain from spills, leaks, system failures, and vapor diffusion. To minimize the overall risk from oxygen scavengers, catalyzed sodium sulfite should be employed preferentially instead of hydrazine. Hydrazine use should be restricted to boilers operating above 900 psig.

5.16.4 Humidification Systems.   Special caution should be observed when using live steam in humidification systems. Problems have been experienced with additives such as morpholine and diethylaminoethanol (DEAE). Both the **American Hospital Association** and the **Joint Commission on Accreditation of Hospitals** *mandate* that the chemicals used to treat boiler water in hospital steam systems employed for steam humidification, food services and instrument sterilization *shall* meet or exceed the standards of the **Food and Drug Administration** for food contact (see next paragraph).

5.16.5 Food Contact.   Special care should be observed where steam may come into direct contact with food. Under the Code of Federal Regulations (Title 21, Section 173.310), boiler water additives may be safely used in the preparation of steam that will contact food under the following conditions:

  a. The amount of additive is not in excess of that required for its functional purpose, and the amount of steam in contact with food does not exceed that required to produce the intended effect in or on the food.

  b. The compounds are prepared from substances identified below and are subject to the limitations prescribed:

> • Cyclohexylamine - Not to exceed 10 ppm in steam, and excluding use of such steam in contact with milk and milk products.
>
> • Diethylaminoethanol - Not to exceed 15 ppm in steam, and excluding use of such steam in contact with milk and milk products.
>
> • Hydrazine - Zero in steam.
>
> • Morpholine - Not to exceed 10 ppm in steam, and excluding use of such steam in contact with milk and milk products.
>
> • Octadecylamine - Not to exceed 3 ppm in steam, and excluding use of such steam in contact with milk and milk products.
>
> • Trisodium nitrilotriacetate - Not to exceed 5 ppm in steam, and excluding use of such steam in contact with milk and milk products.

  c. To ensure safe use of the additive, in addition to the other information required, labeling must include the common or chemical names, the additives, and adequate directions for use to ensure compliance with all provisions of the regulations.

5.16.6 Permissible Exposure Limits (PEL).   The Occupational Safety and Health Administration (OSHA) has established Permissible Exposure Limits (PEL) (29 CFR 1910.1000) in the air for occupational environments for four of the amines as follows:

  Cyclohexylamine - 10 ppm

2-DEAE - 10 ppm

Hydrazine - 0.1 ppm

Morpholine - 20 ppm

OSHA's PELs are endorsed by the Navy as NAVOSH standards. These exposure limits do not apply to personnel exposed long term, 24 hour per day to amines in the air as would result from humidification with direct steam containing amines. At the request of the Navy, the National Academy of Sciences performed an assessment of the amines morpholine and 2-DEAE. Even through the assessment concluded that definitive data are lacking on the health effects of long-term, low-level airborne exposure to the amines morpholine and 2-DEAE, the following recommendations and conclusions were provided:

- Morpholine and 2-DEAE are strong irritants and have the capacity to be converted to nitrosamines which are known animal carcinogens and are suspected to be carcinogenic to humans.

- Some amines can trigger asthmatic attacks. In addition, inhalation of amines by persons with asthma or with prior exposure to amines are at greater risk to adverse health effects than healthy persons.

- Morpholine and 2-DEAE should not be used in concert in a steam generating system when human exposure to the steam may occur.

- When amines are used in steam generating systems, the air in rooms where the steam is used and the steam condensate should be monitored for the level of amines and the presence of nitrosamines.

- If morpholine, 2-DEAF or other nitrosatable volatile amines are used in steam generating systems where humans may be exposed to the steam, the amounts of amines added should be reduced as much as possible.

- When amines are added to a steam generating system, they should be added continuously in small amounts rather than in one large daily dose to minimize the potential for short-term exposure to higher than permissible limits.

Policy Statement. NAVFAC policy is to prohibit for all new construction and building renovations the use of steam which contains amines for food processing, space humidification, and medical instrument sterilization. (Reference NAVFAC, DPL-90-004, 15 June 1990).

a. Steam for food processing, space humidification, and medical instrument sterilizers should be provided by a separate boiler(s) without amine treatment

or, if high pressure steam or high temperature hot water (HTW) is available from a central source, a heat exchanger(s). Location of the boiler(s) or heat exchanger(s) should be based on the most economical method of distribution for the number and location of equipment and humidification stations served.

b. Another alternative for space humidification is the use of heated pan humidifiers which use steam, hot water, or electric coils to generate the steam indirectly. Moisture eliminators will be required to prevent water droplet carryover into the air stream due to vigorous boiling action within the pan if high pressure steam or HTW is used.

c. Make-up water for the oilber(s), heat exchanger(s) or heated pan humidifiers should be from a soft water source, if available, to minimize scaling. The decision to use soft water should be based upon an evaluation of the cost of maintaining the boiler(s), heat exchanger(s), and humidifier(s) without a soft water supply versus providing or increasing the size of the water softener equipment. Automatic blowdown should be provided on pan type humidifiers to assist in reducing scaling even if soft water is used.

d. Since most of the amine free steam will be consumed in the processes, it is unlikely that a condensate return system can be justified, In addition, since corrosion of steam piping is minimal without amine treatment, special piping materials are not required for steam distribution. However, if it is determined that a large percentage of the condensate is available for return, an economic evaluation of its return using fiberglass reinforced plastic (FRP) pipe meeting the requirements of MIL SPEC MIL-P-28584B should be performed. FRP should only be used for pumped return systems since the material can be damaged from steam blowing from failed traps in direct return systems. The FRP can be specified to be factory insulated thereby reducing the field labor required for installation and improving the quality of construction.

e. Atomizing humidifiers should not be used as an alternative to direct steam or heated pan type humidifiers. The atomizing type humidifier has the potential of injecting the legionnaire bacillus as well as other pathogenic microorganisms into the air conditioning air distribution system.

f. An alternative to using central steam for sterilizers is to provide small, dedicated, steam-to-steam heat exchangers at each sterilizer. These too should be provided with a soft water supply to minimize scaling.

g. Apply the above guidance as appropriate to all projects that have not progressed beyond 35% design and to other projects as schedule and funds permit. See NAVFACINST 11300.3F for guidance on existing facilities.

5.16.7 <u>Summary.</u> The use of amines in steam that may be used for humidification or that may come in contact with food should be discouraged. If the use of steam for humidification or food processing is unavoidable, appropriate heat exchangers should be employed to keep the amine laden steam from coming into direct contact with foodstuffs or from being inhaled by humans. The use of hydrazine as an oxygen scavenging agent should be avoided unless mandated for use on a high pressure steam using demineralized water for makeup. There are only minimal safety concerns with the storage and handling of sodium sulfite. The design of all systems associated with the storage and handling of hydrazine must be signed off by a professional engineer specializing in such matters to insure that all requirements of applicable regulations are met.

The use of neutralizing amines (e.g. morpholine and cyclohexylamine) should be restricted to concentrations of these chemicals less than 40% water by weight. The prohibitions against excessive levels of neutralizing amines should be relatively easy to attain because of the low levels required for control of acid attack. in condensate systems. If excessive levels of neutralizing amines are needed for proper pH control of returning condensate, then consideration should be given for the installation of dealkalizers in treating the boiler makeup water. Filming amines should not be part of a typical water treatment program at a boiler plant.

CHAPTER 6. WASTEWATER AND EFFLUENT TREATMENT

6.1 WASTEWATER AND ENVIRONMENTAL CONCERNS. Waste products arise from both treatment and cleaning processes. These processes concentrate contaminants and generate potentially toxic waste products. Clarifiers produce sludge from both raw water contaminants and chemical additives. Ion exchangers produce waste streams with high levels of dissolved solids, including regenerant chemicals. Table 6-1 summarizes wastes generated by various water treatment processes.

      6.1.1 Waste Standards. In the United States, very definitive environmental limits are emplaced upon liquid discharges. These Federal, State and Local laws specifically encompass activities at DOD facilities as per RCRA Amendments of November 1984.

      6.1.2 Environmental Considerations. Programs to protect the environment and to conserve water resources have resulted in reevaluations of once-through cooling systems by designers and operating plant officials. Temperature increases of 10° to 20° can be expected in once-through system effluents. A resultant increase in temperature of a receiving body is dependent on its size and the amount of effluent. This is particularly true for large utility plants requiring extensive quantities of water. When thermal pollution problems exist, a cooling tower or spray pond may be added to cool water before discharge. Alternatively, an entire system may be converted to use an open-circulating cooling tower. In other situations, restrictions on use of toxicants or products to control suspended solids reduce the potential for maintaining cooling efficiency on a once-through basis. As water conservation and pollution control programs develop, new, once-through cooling systems will become less attractive. Existing systems will be subject to modification to meet new discharge limits.

      6.1.3 Regulatory Agencies. The **Environmental Protection Agency (EPA),** Office of Pesticide Programs is empowered to regulate all aspects of pesticide application under the **Federal Insecticide, Fungicide, and Rodenticide Act,** as amended. A pesticide is defined as any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest, and any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant. The use of microbiocides for control of microbiological growth in cooling water systems falls under jurisdiction of the act. In accordance with this regulation, microbiocide formulations should be registered with the EPA. In addition, other federal regulatory agencies such as the **United States Department of Agriculture (USDA), Food and Drug Administration (FDA) and Occupational Safety and Health Administration (OSHA)** can regulate chemical composition and use of various household and industrial microbiocides.

TABLE 6-1
Waste Generated by Treatment Processes

Treatment Process[1]	Character of Waste Produced	Waste Volume Percentage Flow	Example of Waste Weight[2] Dry Basis Pounds Solids/1,000 Gallons Processed
Rough screens	Large objects, debris		
Sedimentation	Sand, mud slurry	5-10	
clarification	Usually acidic chemical sludge and settled matter	2-5	1.3
Cold lime softening	Alkaline chemical sludge and settled matter	2-5	1.7
Hot lime softening (+212°F)	Alkaline chemical sludge and settled matter	2-5	1.7
Aeration	Gaseous, possible air pollutant, such as hydrogen sulfide		
F&ration, gravity or pressure	Sludge, suspended solids	2-5 (for packed bed units)	0.1 - 0.2
Adsorption, activated carbon for odors, tastes, color, organics	Exhausted carbon if not regenerated. Small amounts of carbon fines and other solids can appear in backwash. Carbon regeneration is separate process (usually thermal) in which air pollution problems must be met.		
Manganese Zeolite, for iron removal	Iron oxide suspended solids	Similar to other filtration processes	
Miscellaneous, e.g., precoat, membrane dual media filtration fine straining	As in other filters. Precoat waste includes precoat materials.	1-5	0.1 - 0.2 (plus precoat materials when used
Reverse osmosis3	Suspended and 90-99% of dissolved solids plus chemical pretreatment if required		
Electrodialysis	Suspended and 80-95% of dissolved solids plus chemical pretreatment if required	10-50	1.0 - 2.0

TABLE 6-1
Waste Generated by Treatment Processes (Continued)

Treatment Process[1]	Character of Waste Produced	Waste Volume Percentage Flow	Example of Waste Weight[2] Dry Basis Pounds Solids/1,000 Gallons Processed
Distillation	Concentrated dissolved and suspended solids	10-75	1.5
Ion exchange process[4]			
sodium cation	Dissolved calcium, magnesium, and sodium chlorides	4-6	1.3
2-bed demineral-izition	Dissolved solids from feed plus regenerants	10-14	4-5
Mixed bed demineral-ization	Dissolved solids from feed plus regenerants	10-14	5
Internal Processes	Chemicals are added directly into operating cycle. At least a portion of process steam containing added chemicals, dissolved and suspended solids from feed, and possibly contamination from process can be extracted from the cycle for disposal or treatment and recycle.		

[1]**Processes are used alone or in various combinations, depending upon need.**
[2]**Amounts based on application of process to raw water shown in Table 4-1. These values do not necessarily apply when these processes are used in combinations.**
[3]**Feed must be relatively free of suspended matter.**
[4]**There are many variations. Listed here are a few of the most important.**

6.1.4 <u>Summary</u>.   As effluent standards become more stringent, managers must consider ways to reduce volume and to improve quality of effluent discharge. Recycling wastewater provides an attractive answer, especially when considering the following:

- Discharge fees.
- Supply costs.
- Treatment costs.

- Capital required for new treatment facilities.
- Water shortages.

Economic advantages, coupled with effluent restrictions, have increased the popularity of recycling wastewater into recirculating cooling systems. However, it is not simply a matter of changing plumbing and direction of water flow. Cooling system reliability depends on a comprehensive approach to controlling corrosion, scale, and most importantly, fouling of heat exchangers and piping when wastewater is recycled for cooling. Plant operations are dependent on the total effect and interaction of cooling system chemicals, dissolved and suspended solids, wastewater treatment processes, and effluent standards.

6.2 BOILER SYSTEMS. The three main sources of wastewater from boiler water systems are pretreatment wastes, boiler blowdown, and condensate losses. Losses of blowdown and condensate result in energy penalties through lost heat. Chemical shortages, together with discharge volume limitations, prompt reuse of both ion exchange regenerants and rinse waters. Acid and caustic are often saved for reuse in the next regeneration step or for waste treatment pH control. Control is needed to prevent scaling. In general, treatment wastes are precipitated nontoxic salts that can either be discharged in a dilute solution or buried. Discharges must be within latest EPA limits for morpholine. Blowdown and condensate water are better quality than raw water normally fed to a demineralizer system. Consequently, this water is recycled as shown in Figure 6-1. One potential complication that may arise in reuse of boiler blowdown is concentration of iron (and phosphates, if used for internal treatment) in the boiler. Either iron- or phosphate-bearing sludge entering an ion exchange unit can rapidly foul resin, impeding the demineralization process. This eventuality can be handled with carbon filters. Another limitation is blowdown temperature, imposed by demineralizer resin or construction materials. Reducing the blowdown fraction can usually overcome this problem. As an alternative, water can be precooled in a heat exchanger. In this case, some heat can be recovered by heating feedwater. Some plants use lime/soda softening of cooling tower blowdown to reduce calcium, magnesium, bicarbonate, and silica concentrations. By drawing blowdown from the warm return line, the plant can take advantage of improved hardness and silica removal at the higher temperatures. When not using warm softeners, some plants combine blowdown with fresh makeup water in the primary lime/soda softener. This approach is generally more acceptable when makeup water hardness is present as calcium or magnesium bicarbonate. Otherwise, high chloride and sulfate solids develop, creating a corrosive environment in the cooling system.

6.3 COOLING TOWERS. Cooling water systems are the largest users of water, and consequently, are a major source of plant wastewater. Water management calls for high cycles of concentration in cooling tower systems. Conservation can be

6.3.1 Chromate and Zinc Removal. Environmental regulations severely limit chromate discharge, sometimes to a level as low as 0.05 ppm chromium. To meet local regulations, the treatment process should be selected, monitored, periodically reported, and rigorously controlled. Chromium functions as a corrosion inhibitor and, in this state of oxidation, is very soluble and stable. Chromate can be removed from cooling tower blowdown by: chemical reduction and precipitation, electrochemical reduction and precipitation, ion exchange, or reverse osmosis.

Chemical Reduction. Several reducing agents are used to reduce chromate. The most common are sulfur dioxide, ferrous sulfate, sodium bisulfite, and sodium metabisulfite. Hydrogen sulfide, where it is available as a waste material byproduct, occasionally serves as a chromate reducing agent. After the chromate is reduced, the pH of the blowdown stream is raised to 8.5 with lime or sodium hydroxide. At this pH, solubility of chromium hydroxide is essentially zero, and any zinc present is also precipitated. Enough time should be allowed for chromium hydroxide to subside from the water, since this compound is a light flocculent that can take several hours to settle. Subsidence is usually carried out in a lagoon or a conventional clarifier. If desired, a polymer can help clarify the blowdown water. Chromate removal, whether with sulfur dioxide, ferrous sulfate, or other reactant, can be a batch or continuous process. The selection of a particular process depends on: volumetric rate to be treated, availability of chemicals (particularly waste chemicals), environmental considerations, and economic considerations. In the conventional chromate removal process, the sludge generated is environmentally and economically important. Sludge is expensive to dewater, a procedure that should precede disposal. In many areas, chromium sludge is not allowed in land fill disposal sites.

Electrochemical Reduction. A chromate removal system based on the use of sacrificial iron electrodes is commercially available. Direct current imposed on iron cathodes and anodes produces ferrous hydroxide. The electrochemical process can tolerate a wide influent pH range of 6.0 to 9.0. Hydrogen is evolved from the cell, leaving excess hydroxyl ions that raise the pH of the water by as much as 0.5 unit. The power requirement is 5 to 7 kilowatt hours per pound of chromate as chromium (Cr); the iron electrode requirement is 3.5 pounds of iron per pound of chromate as Cr. About 85 percent of operating costs are for electrode replacement and 15 percent for power.

Ion Exchange Processes. Chromate in cooling tower blowdown exists as a relatively stable and soluble anion. It can be selectively removed in ionic form by exchange with chloride, sulfate, or hydroxide on special resins, and recovered for further use. A schematic diagram of a typical ion exchange process is shown in Figure 6-2. Suspended solids can cause fouling and degradation of weak base resin. Since cooling tower water contains substantial amounts of suspended solids, it must be filtered before reaching the ion exchange beds. Adjusting pH
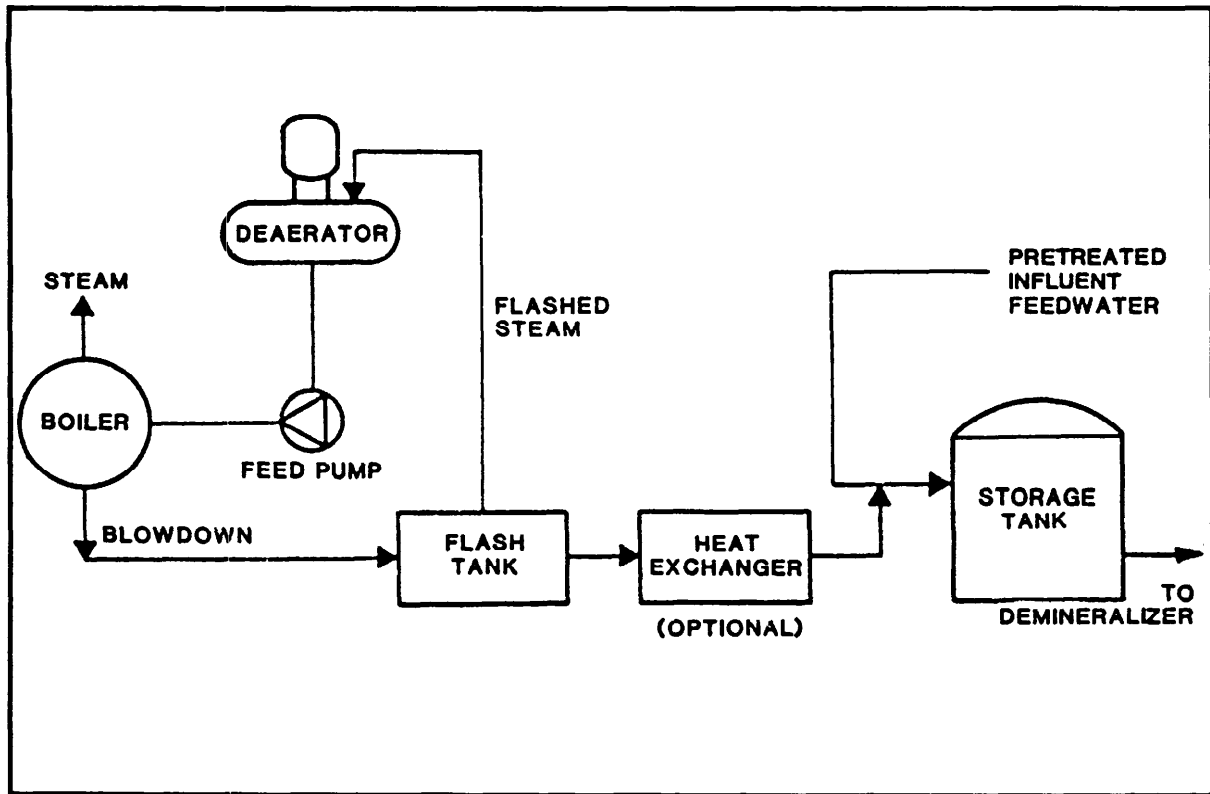
FIGURE 6-1
Boiler Blowdown Recovery

partially achieved by eliminating indiscriminate blowdown to waste of recirculat-
ing cooling water used for pump gland cooling, continuous sample coolers, and
pad washdown water. Such waste of cooling water increases the cost of makeup
pretreatment, cooling water chemicals, and waste treatment. Cascading, or reus-
ing cooling water blowdown, can reduce wastewater and treatment costs under
certain circumstances. With proper pretreatment, effective recirculating water
treatment, and control at high cycles, cooling towers help conserve water. Con-
servation is further aided by reuse of waste streams as makeup. Blowdown
water should usually be processed to comply with environmental regulations
before it is discharged. Water is removed from cooling tower systems either
continuously or intermittently, to prevent scaling and fouling. This blowdown
water contains suspended solids, concentrated salts, metal oxides, and corrosion
inhibitors, along with dispersants and microbiological agents. Because
chromate and zinc are prominent constituents of many effective cooling tower
corrosion inhibitor programs, a discussion of blowdown treatment involves
chromate removal or recycle. In some chromate treatment systems, blowdown
water is prepared for discharge by coprecipitation or exchange of other poten-
tial contaminants. Whatever the treatment, it is important to consider all aspects
of environmental regulations for any particular blowdown stream.

6-5
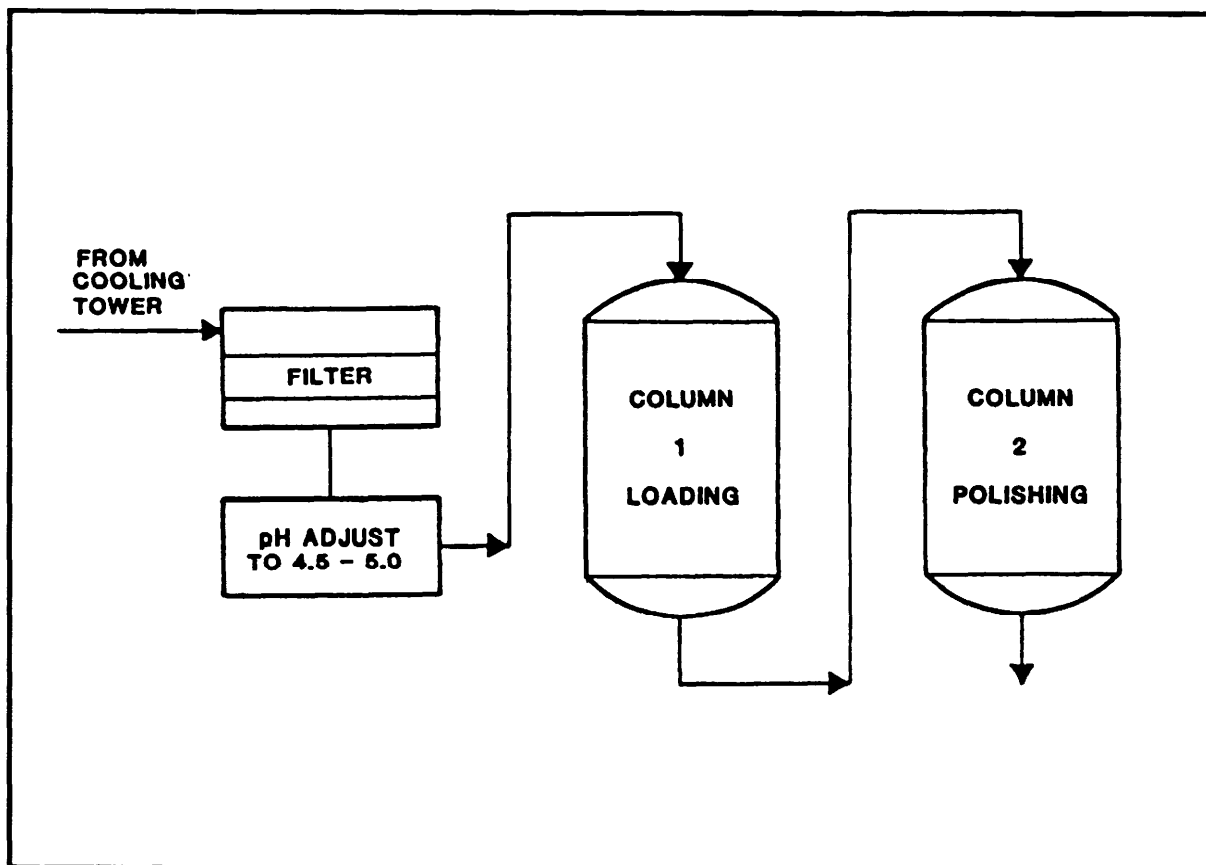
FIGURE 6-2
Typical Ion Exchange Process
(Courtesy Betz)

to a level of 4.5 to 5.0 increases the holding capacity of the exchange resin The pH can be adjusted by adding acid or using a hydrogen cation unit. The overall operational cost for a weak base process depends, to a great extent, on the life of the resin. Resin replacement cost can be one to two times the chemical cost range, depending on influent water quality and operating conditions. The value of the recovered chromate, when reused as the cooling tower system corrosion inhibitor, can offset operating costs. A weak base anion resin system does not remove trivalent chromium or zinc. If these metals have to be extracted from the blowdown before discharge, a cation exchange unit can be superimposed on the system. In addition to the value of the recovered chromate, one of the chief advantages of the ion exchange process is that sludge is not produced. Thus, fluid streams, such as rinse and backwash, can be returned to the cooling tower.

Blowdown Softening. A practical process for plants using chromate as an inhibitor and still meeting stringent environmental regulations is blowdown softening with lime and soda ash. The effluent water can be reused in the cooling system as makeup. A major advantage is recycling of the chromate to the tower system in the processed blowdown. A system of this type can approach zero

blowdown where it is possible to limit losses to softener sludge and tower windage. Such tower losses are indicated in Figure 6-3. Various process schemes are possible with blowdown or side-stream softening (Figure 64). The quality of the makeup water and the tolerance of the cooling system metallurgy
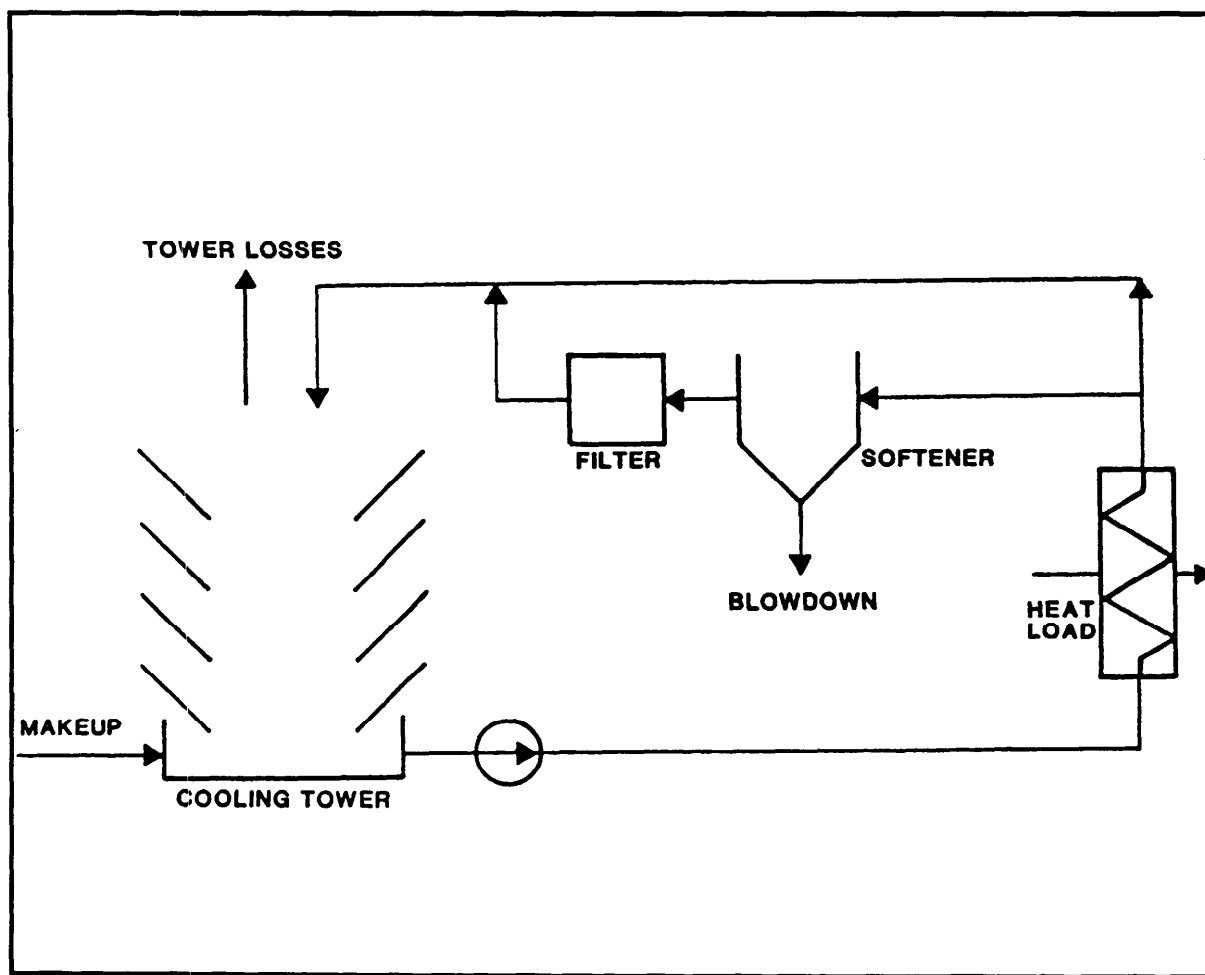
FIGURE 6-3
Chromate Recycle Blowdown Softening

for dissolved solids are important factors to consider. High feed rates of lime or soda ash are required and the effluent can show higher hardness or alkalinity. One serious disadvantage is disposal of the volume of sludge from the softener. Any chromate included in the sludge can cause a disposal problem. In general, to determine whether blowdown softening is the best course to pursue, economics of a specific plant should be studied, along with appropriate pilot testing.
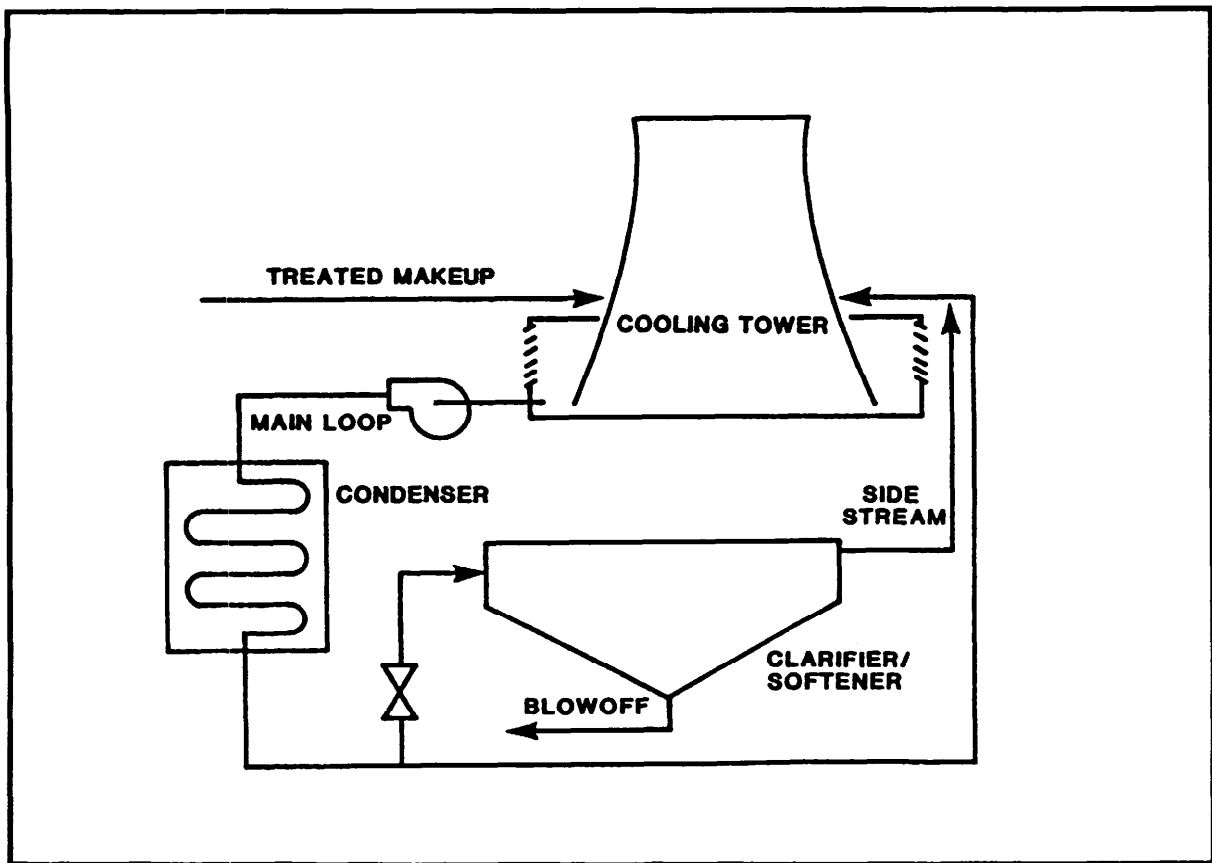
FIGURE 6-4
Side-Stream Softening

6.3.2 Chromate Alternatives. Chromate, long a favorite method of corrosion control, is now unfavorable because of the difficulty of removing it from waste streams prior to discharge. Alternate methods are now preferred that are as good or better than chromate, and have less environmental impact. These are aminoethylene phosphonates (AMP), sodium molybdate, and numerous non-heavy metal inhibitors. Considerable success has been obtained with combinations of materials, notably with AMP and molybdates, primarily because of their synergistic effect. Insoluble starch xanthate (ISX), developed by the U.S. Department of Agriculture, has proved to be one of the simplest and most effective ways to remove heavy metals from water. It can be used as either an additive or a precoat material on a filter. ISX exchanges sodium and magnesium ions upon contact with heavy metal ions. ISX containing the trapped ions is then removed from the water by precipitation or filtration.

CHAPTER 7. MEASUREMENT OF WATER QUALITY

7.1 INTRODUCTION. Industrial water is usually analyzed to determine concentration of impurities that may contribute to corrosion, deposition, or other undesirable reactions and also measures effectiveness of corrective treatments and identifies impurities to help establish a treatment strategy. Test results should be compared to prescribed limits and any deviation should be interpreted so that corrective measures can be taken. The type of tests, frequency, and control limits will vary, depending on the system. There are two types of water quality analyses: sampling with laboratory analysis and manual or automatic monitoring. If extensive monitoring instrumentation is installed, laboratory analysis may be used only to check instrument readings. If little on-line instrumentation is used, a sampling and analysis program should be comprehensive. The balance between analysis and monitoring programs is determined by the size and type of system. Detailed laboratory procedures are beyond the scope of this publication, but AF Regulation 91-40, **Industrial Water Treatment,** addresses many specific procedures in this area.

7.1.1 Sampling and Laboratory Analysis. Diagnosis of water problems requires considerable information about the system. To determine which materials should be removed or added to water to render it suitable, several things are needed: a thorough, accurate analysis of makeup water, system water, deposits, and sections that have been removed from operating systems; and information on the size, design characteristics, and operating conditions of the system. Once the raw water supply has been chosen and a treatment system established, a control testing program ensures adequate treatment rather than expensive overtreatment. A control testing schedule can vary from a simple color comparison for chromate in a closed cooling system, to an elaborate determination of a dozen or more ions measured as micrograms per liter in a supercritical boiler. Samples taken should be stored in accordance with accepted laboratory procedures to ensure accurate analysis. The control program should be tailored for each individual case. For example, analysis for only chloride and phosphate concentrations may be necessary for treatment control in one type system, whereas a very high-pressure boiler may require analyses for alkalinity, chloride, copper, hydrazine or sulfite, iron, morpholine, pH, phosphate, sulfate, and other constituents. Table 7-1 lists many possible determinations performed to control the quality of water destined for steam generation, heating, cooling, and other manufacturing processes.

7.2 METHODS OF ANALYSIS. A detailed explanation of specific laboratory analytical procedures is beyond the scope of this publication, but AF Regulation 91-40 does address many of the requisite tests. Methods of analysis in the following paragraphs give an overview of analyses associated with industrial water treatment.

TABLE 7-1
Frequent Water Quality Determinations

Determination	Boiler Water Feedwater, Condensate	Cooling Water*	Industrial Process
Acidity	X	X	X
Alkalinity:			
Hydroxyl (OH)	X		X
Phenolphthalein (P)	X	X	X
Total: Methyl Orange or			
Mixed Indicator (M)	X	X	X
Ammonia	X		X
Boron		X	X
Calcium	X	X	X
Carbon Dioxide	X		X
Chloride	X	X	X
Chlorine, residual		X	X
Chromium, hexavalent		X	X
Color			
Copper	X	X	X
Fluoride		X	X
Hardness	X	X	X
Hydrazine	X		
Iron	X	X	X
Lead			X
Magnesium	X	X	X
Morpholine	X		
Nickel			X
Nitrate	X	X	X
Nitrite	X	X	X
Octadecylamine	X		
Oil and grease	X	X	X
Oxygen, dissolved	X		X
pH	X	X	X
Phosphate:			
Ortho	X	X	X
Poly	X	X	X

TABLE 7-1
Frequent Water Quality Determinations (Continued)

Determination	Application		
	Boiler Water Feedwater, Condensate	Cooling Water*	Industrial Process
Residue, total (103°C):			
Filtrable	X	X	X
Nonfilterable	X	X	X
Silica	X	X	X
Sodium	X	X	X
Specific Conductance	X	X	X
Sulfate	X	X	X
Sulfide		X	X
Sulfite	X	X	X
Tannin and lignin	X		X
Turbidity			X
Zinc	X	X	X

*Recirculating (open and closed systems) or once-through

7.2.1 Suspended Solids. A gravimetric procedure should be used for quantitative analysis. In many cases visual inspection and descriptive terms (clear, hazy, cloudy, turbid) are used.

7.2.2 Soluble Solids. A gravimetric test is most accurate, but lengthy. An electrical conductivity test gives quick, simple, and reasonably dependable results. Periodic gravimetric tests establish factors for converting electrical conductivity into ppm soluble solids.

7.2.3 Total Alkalinity. A titration test with an acid reagent is used with methyl orange as an indicator. The end point is a pH of 4.5 units. The test measures the alkaline capacity of a solution to buffer decreases in pH.

7.2.4 Phenolphthalein Alkalinity. A titration test with an acid reagent is used with phenolphthalein as an indicator; it gives a sharp end point at about 8.3 units of pH. The test measures the contribution to alkalinity from hydroxyl ions and half of the carbonates.

7.2.5 Hydroxide Alkalinity. Two titrametric methods are available. The simplest, using barium chloride, is accurate to 10 percent. A lengthy strontium chloride method is accurate to about 2 percent. The test measures the contribution to alkalinity from hydroxyl ions alone.

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7.2.6 pH.   Calorimetric tests are accurate to about 0.1 pH. Electrometricmethods using glass electrode assemblies with a meter are more sensitive and accurate. Faults with apparatus not readily discernible can introduce sizable errors, but these can be minimized by calibrating the instrument with known reference solutions. The pH value of a solution can be continuously recorded.

7.2.7 Chloride.   There are several titrametric methods. One method uses silver nitrate with potassium chromate indicator. Another employs mercuric nitrate and diphenylcarbazone. Both are reasonably accurate for solutions with wide ranges in chloride content. For water with low chloride content, the more sensitive mercuric nitrate test is preferred.

7.2.8 Hardness.   The versenate or EDTA titrametric method is extremely sensitive, accurate, and relatively simple.

7.2.9 Sodium Sulfate.   Gravimetric, photometric, and titrametric methods are used. The gravimetric procedure is too time consuming for routine work and photometric tests are not accurate enough. The titrametric method using benzidine is sufficiently accurate for general use and is reasonably fast.

7.2.10 Sodium Nitrate.   The calorimetric method uses a color comparator or electrophotometer.

7.2.11 Sodium Sulfite.   One titrametric method uses N/40 iodine and N/40 sodium thiosulfate. A preferable method uses standard potassium iodate; a modification is available for low sodium sulfite values near 0 to 5 ppm.

7.2.12 Phosphate.   Various color comparison methods are used with special color apparatus or an electrophotometer. Color comparators are relatively inexpensive, accurate, and easy to use; the test is rapid and generally accepted.

7.2.13 Silica.   There are several calorimetric methods to choose from; gravimetric tests are too lengthy. Nessler tubes, color comparators, or electrophotometers can each measure color intensity. The silicomolybdate color test is most widely accepted and rapid, but requires skill.

7.2.14 Dissolved Oxygen.   The Schwartz-Gurney modification of the Winkler procedure is one accepted method. This test demands considerable technical skill and is quite lengthy, with special equipment required. The indigo carmine calorimetric method is a new development. Short and simple to run, it is limited to a range of 1.0 to 50 ppm dissolved oxygen. For trace oxygen determinations in deaerator evaluations, vacuole reagents analyzed photometrically are very accurate down to several parts per billion of dissolved oxygen.

7.2.15 Carbon Dioxide.   Several titrametric methods are accurate only if carbon dioxide is the sole acidic constituent present. All are reasonably simple but require careful handling for dependable results.

7.2.16 Ammonia.   Direct Nesslerization and measurement of developed color intensity in a calorimeter is rapid and accurate, but dependable only with unbuffered water.

7.2.17 Hydrogen.   Testing of gas thermal conductivity is a basic method. Results measure decomposition of steam in high-pressure boilers, but require considerable skill to evaluate.

7.2.18 Steam and Vapor Purity.   Gravimetric tests, throttling calorimeter readings, electrical conductivity measurements, and tracer techniques are available. Conductivity measurements are most common, but specialized sampling apparatus is needed and sensitivity is limited at high purities. For steam purities of 1.0 ppm maximum solids this procedure is satisfactory. If more precise results are required, sodium tracer techniques are used. If sodium salts predominate in the boiler water, flame photometer tests will detect sodium to 0.0002 ppm This method is confined to limited spot checking, in most cases, but can be continuously recorded.

7.2.19 Hydrazine.   Calorimetric tests are used with a comparator or electrophotometer. A special sampling technique is involved and the test is lengthy.

7.2.20 Morpholine.   Using a calorimetric method, a lengthy test is performed using an electrophotometer. Requires technical skill.

7.2.21 Iron.   A calorimetric method using orthophenanthroline and an electrophotometer a fairly common procedure.

7.2.22 Copper.   Several calorimetric methods are used. Diethanolamine and carbonate testing both require an electrophotometer and skilled technique; a calibration curve must be prepared.

7.3 SAMPLING GUIDELINES. Location and design of sampling points requires careful attention. Error will nullify all other efforts at boiler water control, producing results that may be erratic and misleading. Sampling points should usually be located at input and output of important equipment in the cycle such as heaters, boilers, and condensers. Figures 7-1A through 7-1C show sample point locations for several typical cycles. Frequency of sampling varies widely; the number of samples taken per test may be as high as 10 to ensure dependable data. Continuously recorded results are justified at important points; at other points a single daily test is sufficient. A careful review of the cycle dictates fre-
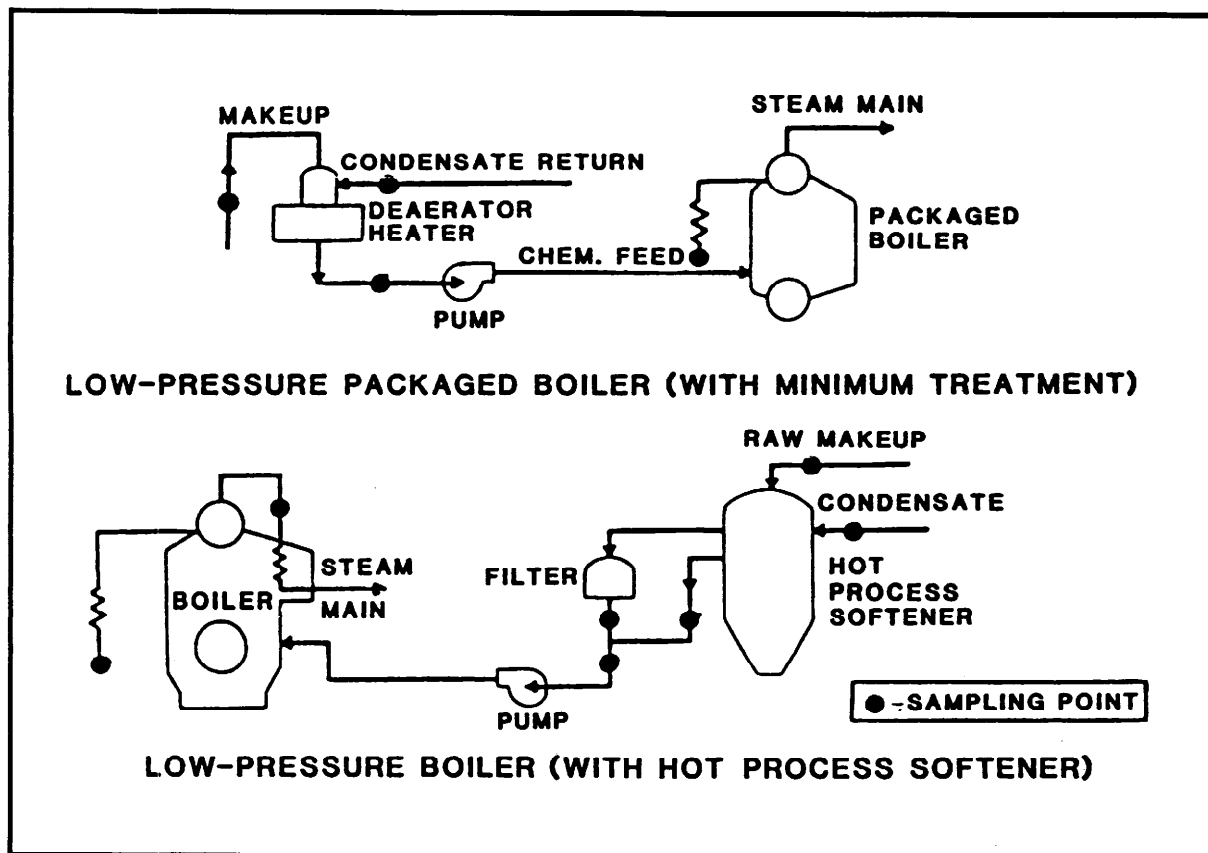
FIGURE 7-1A
Sampling Point Locations for Typical Cycles
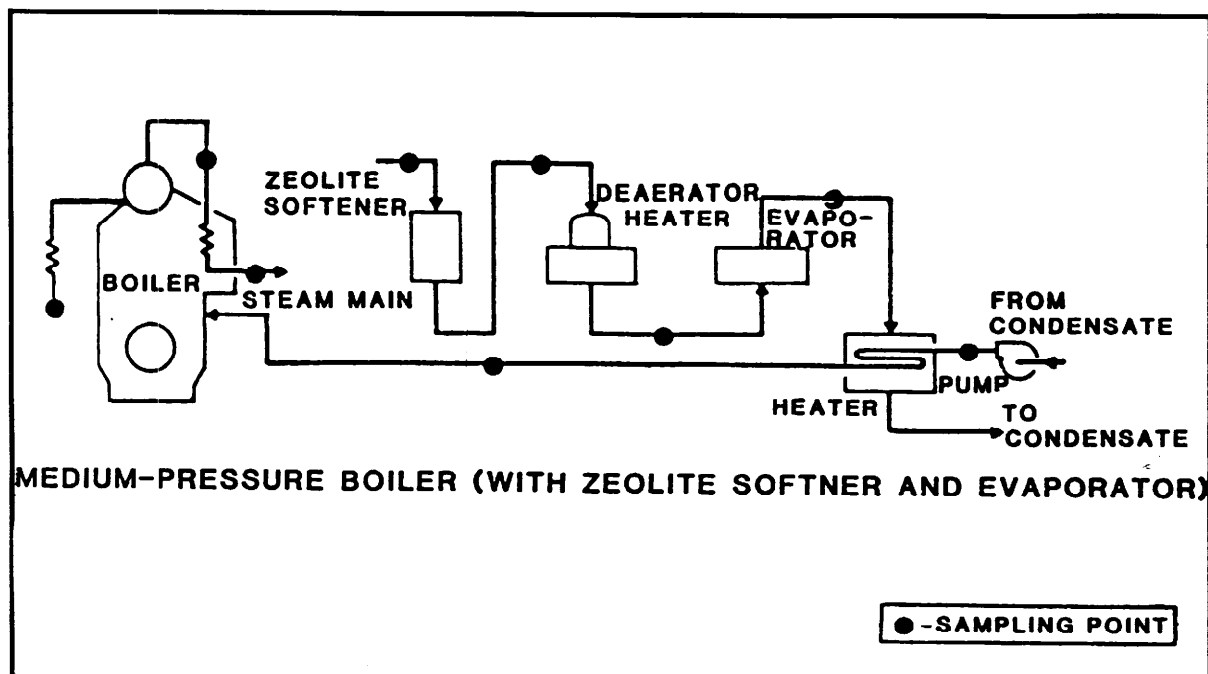
FIGURE 7-1B
Sampling Point Locations for Typical Cycles
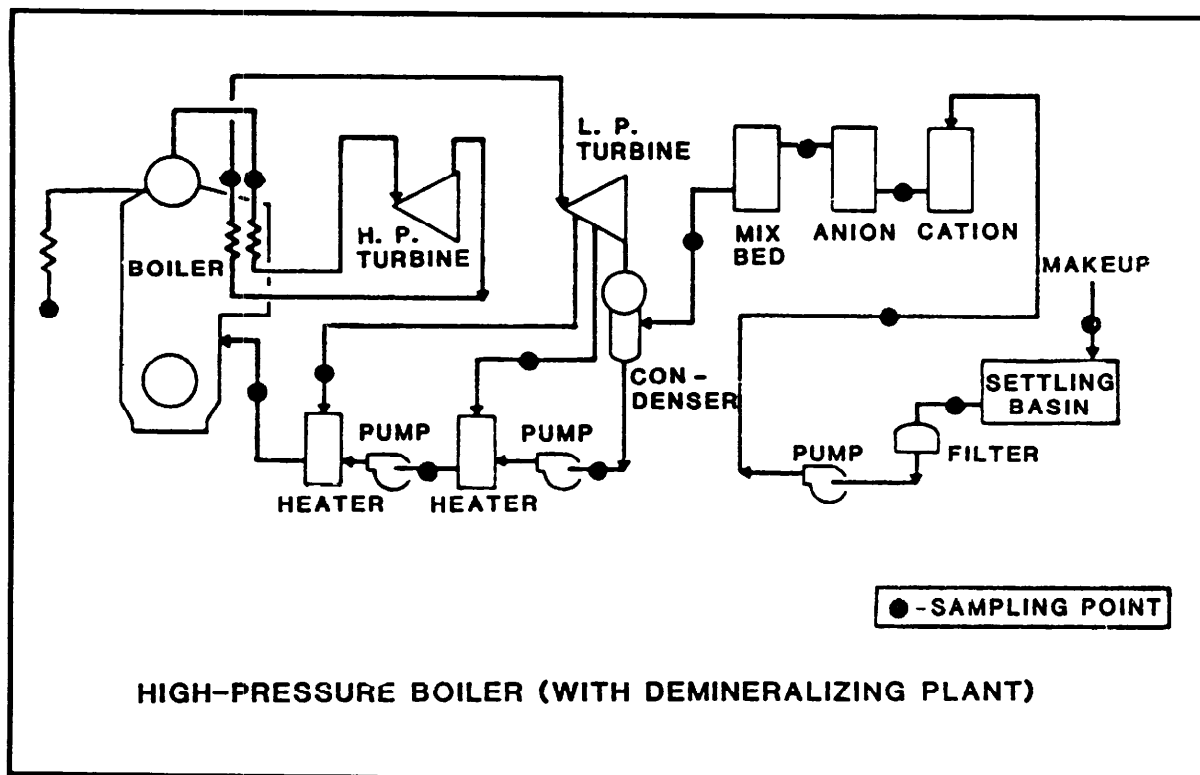
FIGURE 7-1C
Sampling Point Locations for Typical Cycles

quency of tests. Installation of continuous recording meters should be considered; they reveal erratic plant operation that may not be detected by periodic testing. Automatic chemical analyzers are available as supplements to conductivity, pH, dissolved oxygen, and hydrogen recorders.

7.3.1 Gathering Samples. In gathering samples, care should be taken not to contaminate the water before testing. Design of the sampling point should take into account the type of sample and tests to be run. The sampling techniques in the following paragraphs should be used to reduce errors.

Water Tanks. Several samples should be taken at different depths because water quality may vary in a tank.

Piping Runs. Water from pipelines can usually be tapped with simple sampling connections. Where water supplies combine or where chemicals are introduced, the sampling point should be far enough downstream to allow complete mixing.

Boiler Drums. Water from boiler drums is usually sampled with a completely submerged perforated pipe extending the length of the drum. Areas adjacent to the feed inlet or chemical injection lines should be avoided. Samples should be

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cooled to prevent flashing.

Sample Handling. Sample lines should be thoroughly flushed 2 to 5 minutes before sampling. Time varies depending on length of line, pressure, flow, and sampling frequency. Chemically resistant glass or plastic bottles should be used (plastic for silica tests). The bottles should be filled and rinsed twice, then allowed to overflow long enough for three changes of water. Stoppers are put in immediately. Where air contamination would destroy test results, the sample bottle and stopper are submerged to avoid air bubbles. Samples are tested as soon as possible. Where several available methods will produce needed data, the method is selected that gives minimum required accuracy, and that can be run as quickly as possible at least cost. The testing schedule should be reviewed regularly. Sometimes new test procedures are added, but even though certain tests are no longer used in plant operation, they are not necessarily eliminated. Periodic reviews of testing programs are useful to eliminate unnecessary work.

7.3.2 Care of Test Equipment. Apparatus used for testing should be clean and in good repair. Careful cleaning of equipment after use and rinsing glassware prior to use, helps ensure accurate results. Containers of test reagents and indicators should be kept tightly closed when not in use and care should be exercised to avoid contamination Never pour unused reagent back into a storage container. It is good practice to discard reagents after 6 months and restock with fresh supplies. To ensure compatibility and solution strength, test reagents, indicators, and other supplies should be obtained from a single source (usually a test equipment supplier or a treatment consultant).

7.3.3 Location of the Test Station. Site selection and basic equipment for the test station are important aspects of a water treatment program For most installations, the test station need not be elaborate; however, it should meet the following requirements.

- The area should be well lighted. Daylight type fluorescent lighting is preferred.
- The work surface should be sturdy, level, and of sufficient size to provide uncrowded accommodation for test equipment, instruments, log books, and records.
- The location selected should not be in a high traffic area.
- A sink with running water is needed.
- A cabinet to store reagents and test equipment is needed.

7.4 STEAM SAMPLING. Steam purity, particularly for ships, requires a high level of attention. The following paragraphs outline a steam purity investigation program.

7.4.1 Analyzing Steam Purity. Steam purity test results should be carefully interpreted. Although results of a steam purity study indicate that cycles of concentration in a boiler may be increased without causing carryover, cycles should be increased only if boiler cleanliness can be ensured. Often, when steam purity alone is used to determine cycles of concentration, the boiler is found to contain deposits. In such situations, fuel saved by reduced boiler blowdown is offset by fuel lost through the insulating effect of boiler deposits. There are three aspects of steam purity measurement:

- Accurate steam sampling and collection.
- Accurate determination of purity.
- Valid interpretation of data.

7.4.2 Steam Sampling and Collection. Years of research conducted on sampling nozzle design and location have resulted in the nozzle designs specified by the **American Society for Testing and Materials (ASTM)** and the **American Society of Mechanical Engineers (ASME).** Strict adherence to sampling material specifications is mandatory. After selecting a nozzle location, the next problem is to extract the sample correctly. To do this, the rate of sample extraction should be calculated to provide a linear velocity for the sample entering the nozzle equal to the medium passing the nozzle. This method is termed isokinetic sampling. Sampling rates above or below a 1:1 velocity ratio cause distorted stream lines and nonrepresentative sampling. The results may be 50 to 100 percent higher or lower than actual. Steam flow, pressure, temperature, and steam line and nozzle diameters should be considered. Sampling rates should change with significant changes in load. A sample flow rate of 500 ml per minute with normal steam flow can be used in sizing holes in the nozzle, the sample line, and the cooling coil. The sampling line itself should not contaminate the sample and must be of sufficient strength for the service. Line size should be as small as possible to minimize retention time between the nozzle and the final sample collection point. The line should slope downward in the direction of flow. The probe should be inserted horizontally along the centerline of the pipe and perpendicular to the flow. Do not take a sample in a vertical section of pipe (see Figure 7-2). Cooling coils should have sufficient surface to allow adequate cooling and must be capable of cooling the sample under full pressure. If samples are to be collected in bottles for later analysis, the sample should be at 25°C to 30°C (77°F to 86°F) to prevent formation of a vacuum in the sample bottle that could draw in contaminants. Where superheated steam is sampled, some of the condensed, cooled steam should be recycled to desuperheat the steam as close to the sampling nozzle as possible. The sampling bottles should be prepared to ensure absence of impurities.

7.4.3 Analyzing the Sample. The method selected is determined by sensitivity and accuracy required. Basically, there are five methods of measuring steam purity:
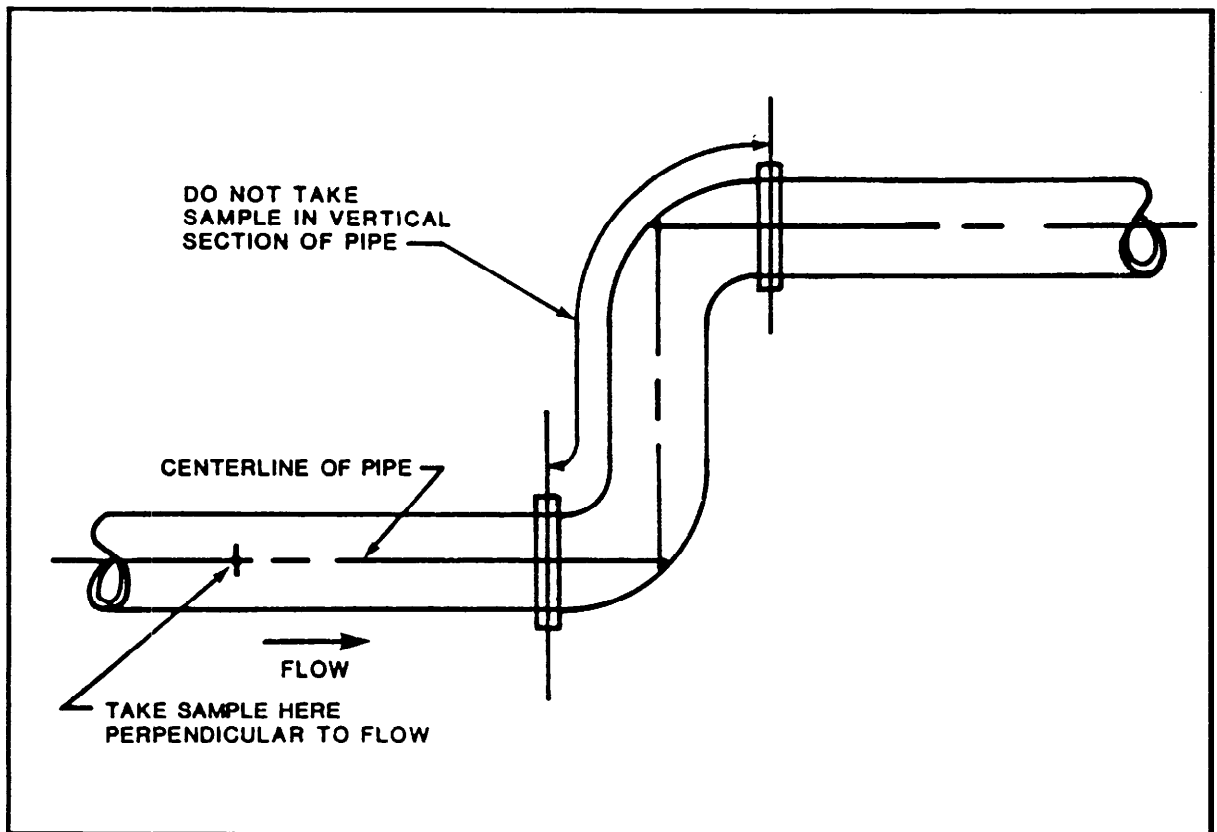
FIGURE 7-2
Position for Taking Steam Sample

- Determination of solids by wet gravimetric analysis of large (4 liters or greater) samples.

- Ion exchange.

- Conductivity.

- Sodium tracer (flame photometry or specific ion electrode).

- Radioactive tracer.

Wet gravimetric analysis is cumbersome, inaccurate, and too time-consuming to be practical. The radioactive tracer method provides optimum accuracy but is very expensive and too difficult to apply. Ion exchange is useful only for determining average carryover during periods of several weeks and often does not distinguish between volatile amines, ammonia, and carbon dioxide. This method does allow for measurement of low levels of all contaminants. Sodium tracer techniques provide precise measurements, with sensitivity as low as 0.1 ppb. The most commonly used measurement method is conductivity. For accurate, meaningful results, the sample should be stripped of gases including volatile amines, ammonia, and carbon dioxide. The Larson-Lane steam analyzer (Figure 7-3), is the most popular instrument for conductivity measurement. The
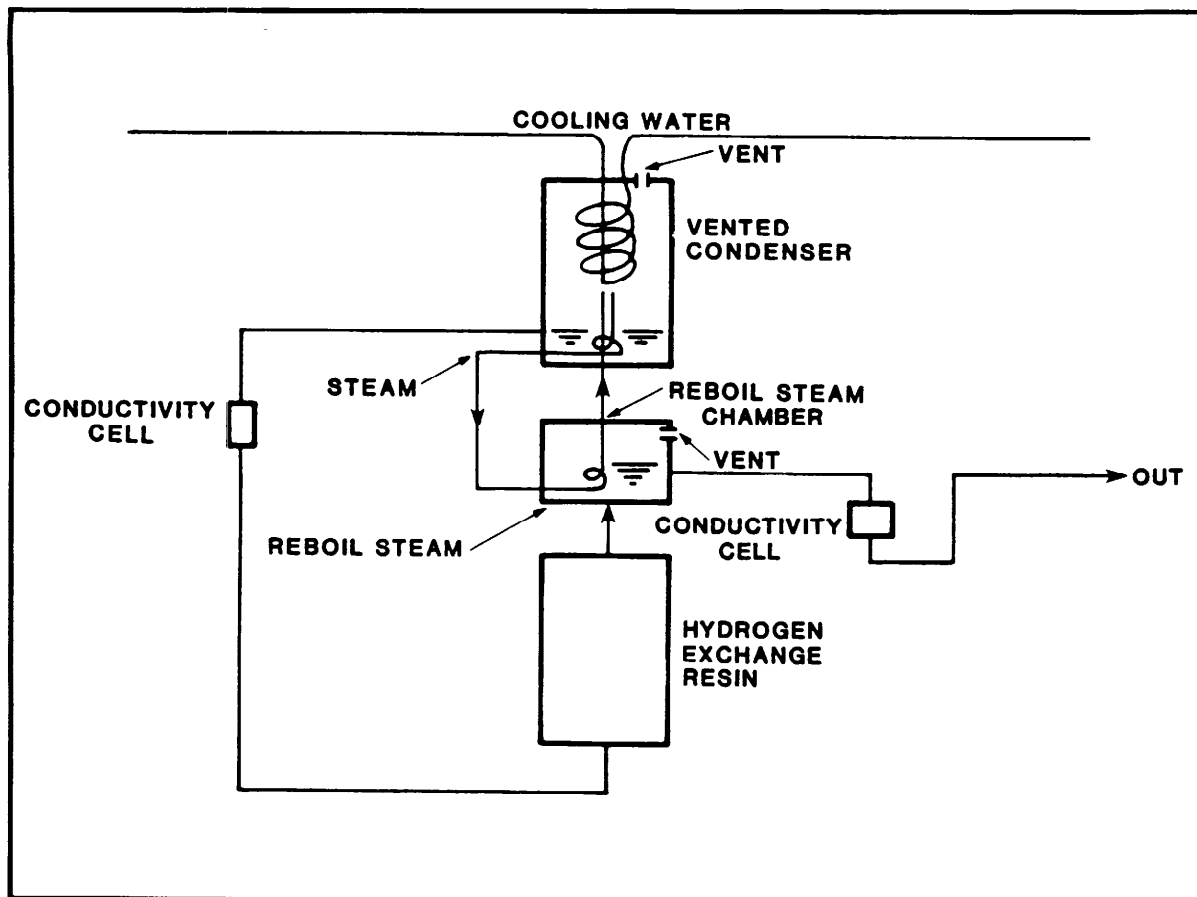
FIGURE 7-3
Schematic of the Larson-Lane Steam Analyzer
(Courtesy Drew Chemical Company)

foregoing comments apply to online sampling and analyzing techniques. Studies can be conducted using the bottle study method. Condensed steam samples are collected in small, specially prepared (triple acid washed) containers for later laboratory analysis. Although the bottle study method is time-consuming and produces intermittent data, it allows impurities other than sodium to be measured. For example, shore-to-ship steam, because of its potential use for blanketing ship boilers and ship feedwater generation, has specific steam purity requirements relative to pH, conductivity, hardness, and silica. Care should be taken to prevent contamination of both the sample and the sample bottle. An inverted funnel can be slipped over the tubing to cover the bottle during filling. The bottle should be opened only at the last moment before sampling, flushed 5 to 10 bottle volumes, filled to overflowing, and the cap rinsed in condensate before being replaced. Labeling with precise sampling time and source is critical for accurate comparison of the sample to steam flow, water level, and boiler water characteristics.

Samples should be taken just before, frequently during, and just after every significant change in operation. Regardless of the analytical method used, sample lines should be flushed 24 hours for a new line (otherwise, 1 hour) to remove contaminants. During actual sample collection, an isokinetic sample flow rate is required.

7.4.4 Conducting the Study. Before beginning tests, a study program should be established, all-inclusive or abbreviated, to suit a particular need. A few variables to consider are as follows:

- Average steam load and steam load at several steady loads above and below average.

- Steam load swings, large and small, fast and slow.

- Water level, average as well as at several points above and below average.

- Boiler water characteristics, particularly TDS.

- Condensate contamination.

- Variation along steam drum, to detect uneven steam release or faulty baffles.

- Internal treatment chemicals.

NOTE

Soot blowing and bottom blowdown can disrupt a steam study and should be avoided while conducting tests.

Variables should be considered individually, and detailed records should be kept during the study. In addition to recording data pertinent to the variables, any fuel change, gas pressure drop, feedwater temperature change, or change in condensate return flow or source should be noted. Strip chart recorders for steam analyzers should be used for online testing. Reference samples of boiler water should be taken at a number of points during the test, especially before and after any change that would have a significant effect on water chemistry. In addition to the regular analysis, sodium and gravimetric solids should be tested when using sodium tracer techniques.

7.5 ONLINE MONITORING.

7.5.1 Automatic Instrumentation. Until recently, most available automatic analysis equipment was designed for laboratory use. The problem with fully automatic measurement was a lack of sufficiently reliable equipment rugged enough for field use. Automatic analytical instruments are now avail-

able for this severe service. Tests for conductivity, pH, dissolved oxygen., phosphate, chromate, hardness, hydrazine, silica, and sulfite have been adapted to automatic control.

Steam Purity Monitoring System. In response to NAVSEA criteria for shore-to-ship steam purity, a steam purity monitoring system (SPMS) was developed by the Naval Civil Engineering Laboratory (NCEL). The SPMS consists of continuous, inline analysis of pH, conductivity, hardness, and silica through isokinetic sampling. The system produces a continuous hard copy of condensate chemical analysis for review and appraisal. A chemist, technician, or boiler operator can maintain the system For a summary of the SPMS, refer to NCEL **Technical Memorandum** 53-86-13, **Steam Purity Monitoring System: Operational Test Report,** dated March 1986, (Figure 7-4).

Continuous Sampling. Continuous sampling eliminates need for collecting, handling, and storing of individual samples as experienced in the dominant method of grab sampling. Grab sampling also requires hours between sampling and chemical analysis and provides results only at the time collected. The SPMS continuous sampling method uses isokinetic sampling, which provides near real-time conditions every moment of the day, seven days a week. The isokinetic system includes a programmable controller, a steam main and condensate flow meter, and a control valve. The controller senses steam main velocity and adjusts the condensate control valve until it is the same as the sample withdrawal velocity, ensuring isokinetic sampling. The system significantly enhances the need of shore boilers and distributions systems to respond to load swings in ship steam demands.

       7.5.2 Conductivity.   Dissolved solids, also called total dissolved solids (IDS), is a fundamental measure of water quality. Direct continuous measurement of TDS is difficult. Conductivity (in micromhos) is easily measured and is directly related to TDS. However, the sample should be brought to a neutral pH before a valid pH can be measured. Many instruments are available that measure conductivity. Care should be exercised in selecting instruments. Often, a control system with low initial cost will prove most expensive when greater costs of maintenance, replacement parts, and inaccurate control are considered. Instruments now exist that are highly reliable for water treatment applications. These instruments have features that include independent control and alarm settings, meter readout, recorder outputs, and automatic temperature compensation. In open cooling systems and boiler systems, conductivity is used for automatic blowdown control. Conductivity can be used to control an alarm or an automatic dump signal for many kinds of contamination in returned condensate. In many boiler systems, there is a correlation between unneutralized conductivity of the boiler water and TDS levels.
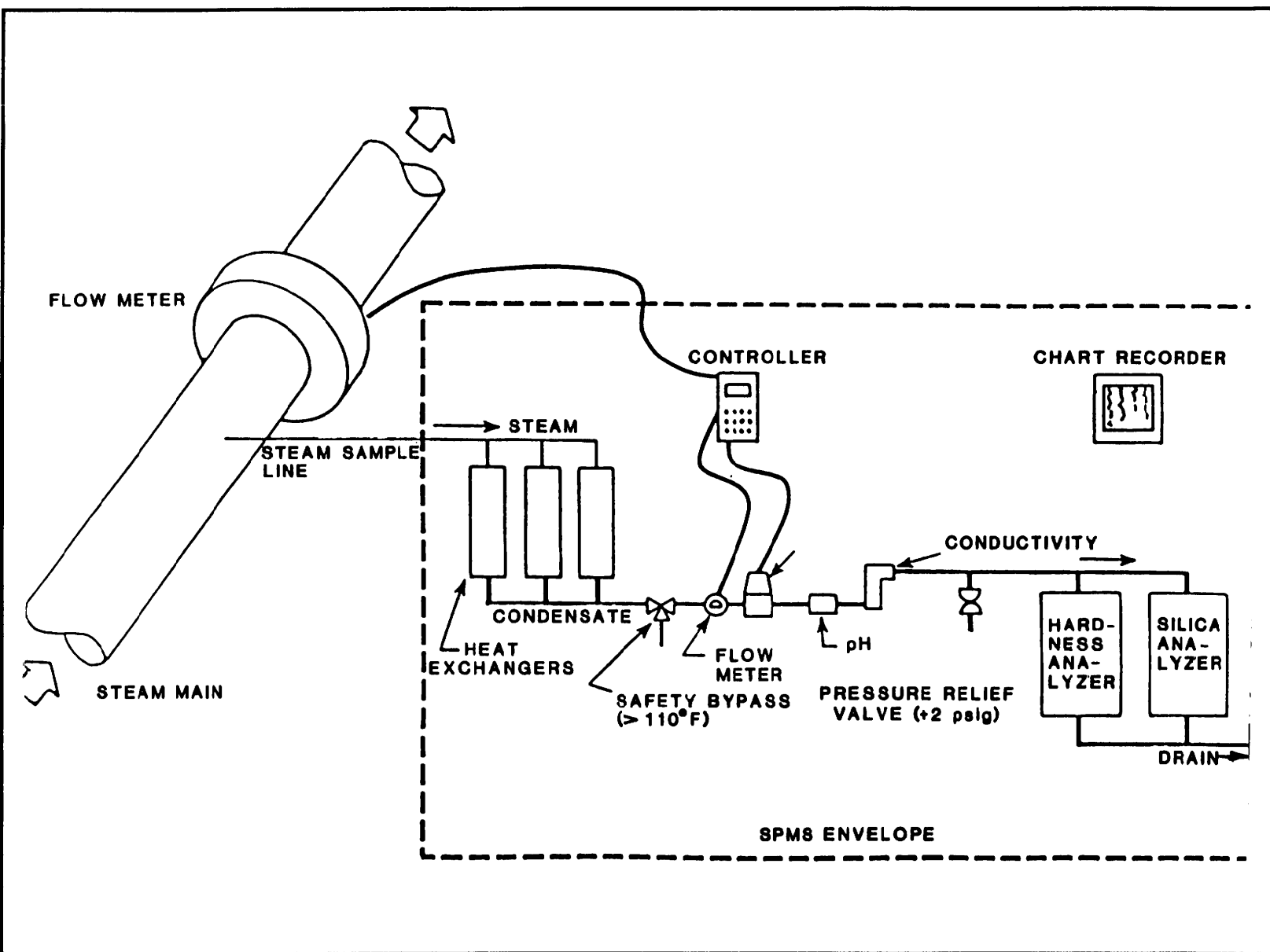
FIGURE 7-4

Steam Purity Monitoring System Schematic (NCEL)

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Conductivity, combined with proper valve design and careful engineering for size, provides a reliable automatic system to control boiler blowdown. Depending on adjustment, the system automatically can open a blowdown valve for preset times (e.g. about 1 minute every 15 minutes). If conductivity 6 above the set point, indicating need for greater blowdown, the blowdown valve can stay open until the conductivity is reduced to an acceptable level.

7.5.3 pH. In cooling tower systems, pH is necessary to control because of the sensitivity of pH to small changes in acid addition A pH measurement often has been ignored whenever possible because of problems inherent in measuring devices. The pH electrodes require frequent cleaning, recalibration of the instrument, and replenishment of reference solution. Electrical problems can occur with the low level signal strength, particularly in humid conditions associated with water systems. Electrode systems using a uniquely designed reference cell and a measuring electrode with integral preamplifier have overcome these problems. By coupling the electrode system with a pH transmitter-controller, a complete pH measurement and control system with high reliability and accuracy can be established.

7.5.4 Wet Analyzers. Certain calorimetric tests, such as those for hardness and silica, have been adapted for continuous analysis. In a wet analyzer, reagents are added to the sample water and time is allowed for reaction and color development. The sample (reagent solution) is then discharged into a chamber where a photocell measures color intensity and corresponding concentration of a specific parameter. The measurement serves as a basis for manual adjustment or remote/automatic regulation. Since the wet analyzer uses a transposed laboratory technique, it requires some care and attention.

7.5.5 Chemical Sensing Electrodes. The glass electrode used for pH measurement was one of the first to be developed to measure chemical concentration by an electrical effect. Other, newer electrodes, are sensitive to specific ions or the presence of dissolved gases. Specific ion electrodes have a high degree of specificity for a single ion and can be used to measure calcium, chloride, fluoride, total hardness, cyanide, and others. However, the electrodes are susceptible to erroneous readings due to the presence of certain interfering ions.

7.5.6 Typical Instrumentation. Figure 7-5 illustrates a recommended water quality monitoring instrumentation scheme for a high-pressure steam power plant. The diagram shows the extent to which automatic analyzers and monitors may be employed. Such complexity is justified only in larger central plants.

7.6 SYSTEM LAYUP. During seasonal or maintenance required shutdown, the system should be properly prepared to prevent corrosion and deterioration. See NAV-FAC MO-209, **Maintenance of Steam, Hot Water, and Compressed Air Systems** for system layup.
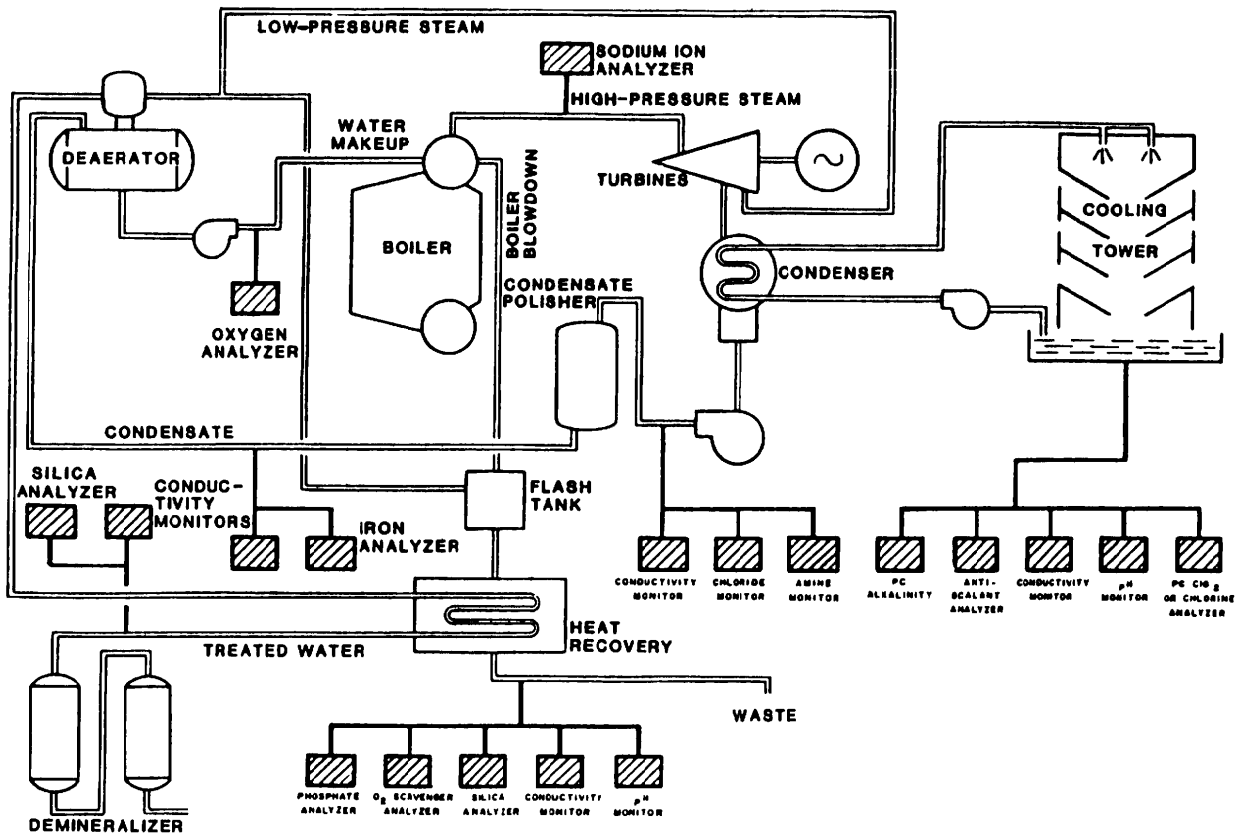
FIGURE 7-5
Analysis System for Large, High-Pressure Boiler Plant.

APPENDIX A

ABBREVIATIONS - ACRONYMS

APPENDIX A
ABBREVIATIONS AND ACRONYMS

ABMA	American Boiler Manufacturers' Association
AMP	Aminoethylene phosphonate
ASME	American Society of Mechanical Engineers
ASTM	American Society of Testing and Materials
°C	Degree Celsius
Ca	Calcium
cc	Cubic centimeter
Cr	Chromium
DEAE	Diethylaminoethanol
ED	Electrodialysis
EDTA	Ethylenediaminetetraacetic acid
EFD	Engineering Field Division
EHSC	Engineering and Housing Support Center
EPA	Environmental Protection Agency
epm	Equivalents per million
°F	Degree Fahrenheit
FDA	Food and Drug Administration
gpd	Gallons per day
HMS	Hazardous Material Information System
HTHW	High temperature hot water

ISX	Insoluble starch xanthate
kWh	Kilowatthour
MBT	Mercaptobenzothiazole
Mg	Magnesium
mg/l	Milligrams per liter
ml	Milliliter
mm	Millimeter
umho/cm	Micromho per centimeter
mpy	Mils per year
uS/cm	Microsiemens per centimeter
MSDS	Manufacturer's Safety Data Sheets
MUSE	Mobile Utilities Support Equipment
NAVSEA	Naval Sea Systems Command
NIOSH	National Institute of Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
pH	Hydrogen ion concentration
pHs	Langelier's saturation pH value
ppb	Parts per billion
ppm	Parts per million
psi	Pounds per square inch
psig	Pounds per square inch gauge
RO	Reverse osmosis

SHMP	Sodium hexametaphosphate
TDS	Total dissolved solids
USDA	United States Department of Agriculture

APPENDIX B

SAMPLE WATER ANALYSIS REPORTS

BOILER PLANT MONTHLY REPORT

MONTH _____ DAY ____ YEAR _____   PREPARED BY:_____

AVERAGE MAKEUP ANALYSIS (DAILY)		NOTES
SILICA (ppm)	| | | | |	
TOTAL ALKALINITY (ppm)	| | | | |	
TOTAL INFLUENT HARD (ppm)	| | | |	
SOFTENER REGENERATION	| | | |	
SALT USED (lbs.)	| | | |	
TOTAL EFFLUENT HARD (ppm)	| | | |	

AVERAGE CORROSION ANALYSIS (WEEKLY)		NOTES
Cu IN CONDENSATE (ppm)	| | | | |	(0.050 ppm max.)
Fe IN CONDENSATE (ppm)	| | | |	(0.100 ppm max.)
AMINE RESIDUAL (ppm)	| | | |	

PERCENTAGES	THIS MONTH	LAST MONTH	DIFF.
FUEL (per million lbs. steam)			
% MAKEUP			
% CONDENSATE RETURN			
% BLOWDOWN			
SALT (lbs. per million gals. water)			
SCAVENGER (lbs. per million gals. water)			
AMINE (lbs. per million lbs. steam)			
CHEMICAL (lbs. per million lbs. steam)			

CHEMICAL USE	BOILER #1	BOILER #2	BOILER #3
#1 CHEMICAL (lbs.)	| | | | |	| | | | |	| | | | |
#2 CHEMICAL (lbs.)	| | | | |	| | | | |	| | | |
#3 CHEMICAL (lbs.)	| | | | |	| | | | |	| | | | |
STEAM PRODUCED (lbs.)	| | | | |	| | | |	
HOURS OF OPERATION	| | | | |	| | | |	

PLANT TOTALS	
STEAM (lbs.)	| | | | |
FEEDWATER (lbs.)	| | | | |
MAKEUP WATER (gals.)	| | | | |
CONDENSATE (gals.)	| | | | |
AMINES (lbs.)	| | | | |
SODIUM SULFITE (lbs.)	| | | | |
CHEMICAL #1	| | | | | | | | |
CHEMICAL #2	| | | | | | | | |
CHEMICAL #3	| | | | | | | | |
TOTAL FUEL (gals. or millions cu. ft. gas)	| | | | | | | | | | |

Comments:

_____
_____
_____
_____

SAMPLE WATER ANALYSIS REPORTS

APPENDIX E

DAILY ANALYSIS RECORD

BOILER No. ____

MONTH _____ YEAR ____ PREPARED BY: _____

BLOWDOWN SPECIFIC CONDUCTANCE (μmho/cm) — 6000, 7000, 8000 (7000)

BLOWDOWN TOTAL ALKALINITY (ppm) — 550, 700, 850 (700)

Alkalinity Not To Exceed 10% of Specific Conductance

BLOWDOWN HYDRATE ALKALINITY (ppm) — 100, 200, 300, 400, 500 (200-400)

BLOWDOWN (pH) — 10, 10.5, 11, 11.5 (10.5-11)

BLOWDOWN PHOSPHATE (ppm) — 20, 30, 40, 50 (30-50)

DAY OF MONTH

B-2

DAILY ANALYSIS RECORD

BOILER No. ___

MONTH _____ YEAR ____ PREPARED BY: _____

			1	5	10	15	20	25	30	

FEEDWATER SODIUM SULFITE (ppm) — scale 0, 10, 20, 30, 40 — (15–30)

FEEDWATER TOTAL HARDNESS (ppm) — scale 0, 0.3, 0.6, 0.9, 1.2 — (0.0)

STEAM (pH) — scale 6, 7, 8, 9, 10 — (8–9.5)

STEAM CONDUCTIVITY (μmho/cm) — scale 10, 20, 30, 40, 50 — (25)

STEAM SODIUM ION (ppb) — scale 0, 10, 20, 30, 40 — (5)

DAY OF MONTH

B-3

Water Treatment Operating Log for Steam Boilers/UFPV's			Activity				Building Number				Boiler Number	
Date	Boiler Operator	Conductivity umhos/cm	P. Alkalinity ppm as CaCO$_3$	Sulfite ppm as SO$_3$	Phosphate ppm as PO$_4$	Cond. pH	Chemicals Added				Make-Up Water Meter Reading	Comments
							NaOH	SO$_3$	PO$_4$	Amine		

Water Treatment Operating Log for Hot Water Boilers				Activity	Bldg. No.
Date	Boiler Operator	pH	Nitrite as NO_2	Nitrite Added	Comments

APPENDIX C

EXAMPLE WATER TREATMENT PROGRAMS

Numerous parameters influence the optimum specification of water treatment chemicals and equipment for a given mechanical system. In this section, seventeen (17) example water treatment programs are provided. These may be used as a guide to facilitate installation of equipment, selection of chemicals, and operation of treatment programs.

Differences may be noted between these example treatment programs and the treatment limits listed in NAVSEA and ASME guidance. The differences are primarily attributed to the fact that small size and low pressure steam boilers are neither capable nor equipped to attain these referenced standards. Thus, the following example treatment programs take into account the typical water treatment equipment condition, manpower availability and experience levels, and boiler sizes that are found at shore facilities. Large boiler plants operating at high steam pressures will not find an example program applicable to their respective condition. In such a case, the ASME and NAVSEA guidances must be strictly complied with in operating the water treatment equipment.

The example programs are as follows:

1. Large steam plants, continuously manned with automatic blowdown controllers.

2. Large steam plants, continuously manned with manual continuous blowdown controls.

3. Medium size steam plants, continuously manned with automatic blowdown controllers.

4. Medium size steam plants, continuously manned with manual continuous blowdown controls.

5. Medium size steam plants, seasonally manned with automatic blowdown controllers.

6. Medium size steam plants, seasonally manned with manual continuous blowdown controllers.

7. Medium size steam plants, seasonally manned with manual blowdown controls.

8. Small size steam plants, unmanned with automatic blowdown controllers.

9. Small size steam plants, unmanned with manual continuous blowdown controls.

10. Small size steam plants, unmanned with manual blowdown controls.

11. High temperature hot water (HTHW) boiler plants.

12. Low temperature hot water closed loop boiler systems.

13. Unfired pressure vessel (UFPV) low pressure steam systems.

14. Closed loop chilled water systems.

15. Large cooling tower systems with automatic acid feed and automatic blowdown controllers.

16. Cooling tower systems with automatic blowdown controllers.

17. Cooling towers with manual controls.

1. LARGE STEAM PLANTS, CONTINUOUSLY MANNED WITH AUTOMATIC BLOWDOWN CONTROLLERS.

A. Treatment Limits For Boilers Operating Below 300 psi

Boiler water will be treated to maintain the following limits:

Parameter	Limits
Alkalinity, Total	700 ppm maximum as $CaCO_3$
Alkalinity, P	250-600 ppm as $CaCO_3$
Conductivity	3,500 umhos/cm (neutralized)
Hardness	< 0.3 ppm as $CaCO_3$
pH	10.5-11.2
Phosphate	30-50 ppm as PO_4
Polymeric Dispersant	As directed by manufacturer (e.g. 1 quart added per thousand pounds of steam generated)
Sulfite	30-50 ppm as SO_3

Automatic conductivity controllers continuously monitor the conductivity of the boiler water. As the concentration of dissolved solids increases, the controller senses the corresponding increase in boiler water conductivity. The controller then increases the flow of blowdown from the continuous blowdown port. This causes an increase in makeup water to the boiler, dilutes the boiler water, and prevents scale formation.

Automatic controllers permit fairly high levels of dissolved solids in the boilers. However, they should be continually checked for accuracy of readings and recalibrated as necessary. A depiction of water treatment equipment for a large boiler plant is provided as Figure C-1.

Produced steam should be chemically treated with neutralizing amines to maintain the pH of returning condensate between 7.5 and 8.5. A mixture of morpholine and cyclohexylamine is typically used for this purpose. Do not purchase these chemicals in concentrations greater than a 40 percent solution. Few power plant personnel have the necessary safety equipment to dilute these reagents from concentrated stocks. Also, avoid purchasing these chemicals in a solution strength less than 30 percent.

Boiler feedwater should be treated by mechanical deaeration in larger steam plants to maintain the dissolved oxygen at less than 0.05 ppm.

Evaluation of sulfite residual will not determine dissolved oxygen concentrations in a boiler. Further, samples of deaerated water should be taken without contamination by sulfite feed into the storage section of the deaerator/heater. For some units, the sulfite feed should be shut down for several hours before obtaining a sample for trace oxygen analysis.
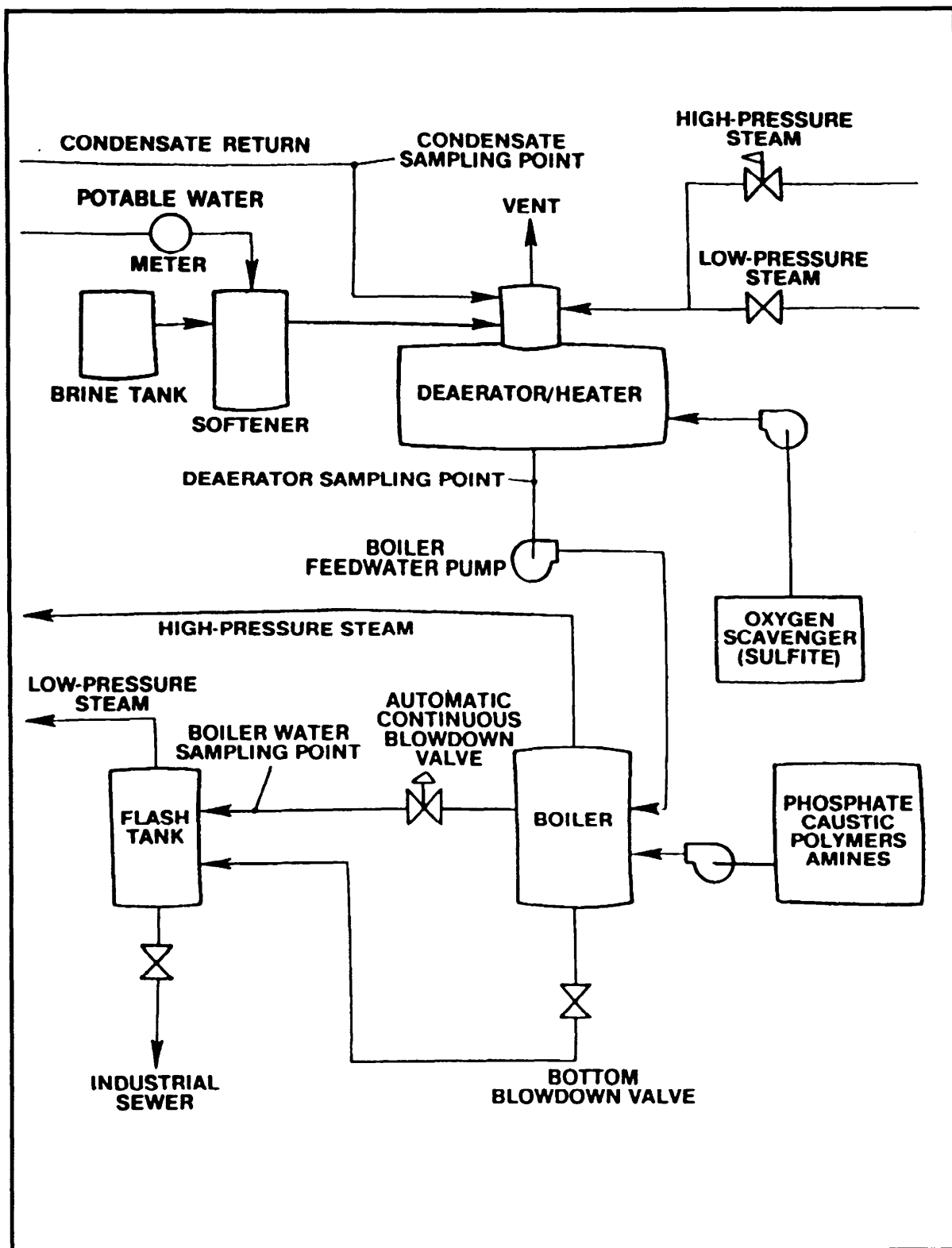
FIGURE C-1

Schematic of water treatment equipment at a large continuously manned boiler plant with automatically controlled blowdown.

B. Chemicals Required

The following table details the chemicals required to implement this program. Note that filming amines are not listed in this table. Filming amine use should be restricted to injection over a period of several hours, in large steam distribution systems immediately before a seasonal shutdown. At plants with chronic condensate line corrosion control problems, satellite injection of filming amines may be needed. However, such a decision should be made only after a comprehensive evaluation of the plant water treatment system is accomplished.

Chemical	Purpose
caustic soda	alkalinity control for boilers with dealkalizers
sodium sulfite with cobalt catalyst	O_2 scavenging
sodium hexametaphosphate	hardness control
neutralizing amine	condensate corrosion control
polymeric conditioner	sludge dispersant

C. Implementation

Public Works personnel have responsibility for implementing steam boiler water treatment programs. Public Works will maintain supplies of caustic soda, sodium sulfite with metal catalyst, and sodium hexametaphosphate. Boiler plant operations personnel are responsible for obtaining these chemicals and maintaining a sufficient stock of chemicals at their respective boiler plants for one to two months of operation.

This section presents the specific procedures for treating the water in a steam boiler. Each Bill of Attendance is presented on a separate page for ease of copying them for the boiler rooms.

The following step-by-step procedures will be performed once per shift for each boiler at the plant.

Step No.	Description
1	On each boiler in operation, open the bottom blowdown valves according to the schedule in use at the plant. After some experience implementing the water treatment program, this schedule may be modified. However, any changes in bottom blowdown schedules must be explicitly approved by the boiler plant supervisor.
2	Turn on the cold water to the boiler water sample cooling coil. Open the specific boiler water line slowly until a steady stream of boiler water is flowing, free of sparging and flashing. Wait approximately two minutes. Slowly fill a clean sample container from the sample cooler, then close all valves.

3   Perform the following tests in order:

        * Conductivity (If conductivity exceeds limits, discard sample and repeat step #1 blowing down the mud drum until within limits.)

        * P Alkalinity (If P Alkalinity exceeds 600 ppm, discard sample and repeat step #1 blowing down the mud drum until within limits.)

        * Sulfite

        * Phosphate

4   Take samples of condensate from the various condensate return lines where the condensate is free of make-up water addition.

5   Analyze the samples of condensate for pH.

6   Record results on water treatment log for each boiler and condensate loop. Use the example forms provided as pages B-2 and B-3 or similar forms. Next calculate the required chemical quantities.

7   Mix the sodium sulfite in softened water, being careful not to aerate; add solution to the chemical feed tank supplying the deaerator and fill with softened water to produce the desired solution concentration. Change the pump stroke or pump speed to maintain the treatment limits.

* 8   Mix the powdered phosphate, liquid polymer and caustic flake with softened water in the proper chemical feed tank and fill with softened water. Adjust the pump stroke or speed to maintain the treatment limits.

9   Adjust the metering pump for the neutralizing amines being injected directly into the steam header.

10   Adjust the automatic continuous blowdown controller setting to maintain the treatment limits. Once per week clean and calibrate the conductivity probes. (When the probe is found to be in excess of 200 micromhos in error, this calibration step may have to be accomplished more frequently.)

11   Record the quantities of chemicals added on a form similar to that provided on page B-4 of this document The water treatment log should include comments or noted discrepancies. Particular attention must be given to changes of settings on chemical feed pumps or to the automated continuous blowdown controller.

        *If the boilers are not equipped with individual chemical feed tanks and pumps, the phosphate, caustic, and polymers are added into the boiler feedwater line servicing all of the boilers. The chemical parameters of each boiler should be considered and the chemical feed pump speed and/or stroke should be changed to maintain the minimum levels of phosphate and caustic in each of the boilers.

2. LARGE STEAM PLANTS, CONTINUOUSLY MAN-NED WITH MANUAL CONTINUOUS BLOWDOWN CONTROLS.

A. Treatment Limits for Boilers Operating Below 300 psi

Boiler water will be treated to maintain the following limits:

Parameter	Limits
Alkalinity, Total	700 ppm maximum as $CaCO_3$
Alkalinity, P	250-600 ppm as $CaCO_3$
Conductivity	3,000 umhos/cm (neutralized)
Hardness	< 0.3 ppm as $CaCO_3$
pH	10.5-11.2
Phosphate	30-50 ppm as PO_4
Polymeric Dispersant	As directed by manufacturer (e.g. 1 quart added per thousand pounds of steam generated)
Sulfite	30-50 ppm as SO_3

Manual continuous blowdown valves permit higher levels of dissolved solids in the boilers than with bottom blowdown alone. However, valve settings should be continually checked. Changes in makeup or condensate return rates significantly influence the dissolved solids level in boilers with a fixed setting on the continuous blowdown valve. A depiction of water treatment equipment for a large boiler plant is provided as Figure C-2.

Produced steam should be chemically treated with neutralizing amines to maintain the pH of returning condensate between 7.5 and 8.5. A mixture of morpholine and cyclohexylamine is typically used for this purpose. Do not purchase these chemicals in concentrations greater than a 40 percent solution. Few power plant personnel have the necessary safety equipment to dilute these reagents from concentrated stocks. Also, avoid purchasing these chemicals in a solution strength less than 30 percent.

Boiler feedwater should be treated by mechanical deaeration in larger steam plants to maintain the dissolved oxygen at less than 0.05 ppm.

Evaluation of sulfite residual will not determine dissolved oxygen concentrations in a boiler. Further, samples of deaerated water must be taken without contamination by sulfite feed into the storage section of the deaerator/heater. For some units, the sulfite feed must be shut down for several hours before obtaining a sample for trace oxygen analysis.

B. Chemicals Required

The following table details the chemicals required to implement this program. Note that filming amines are not listed in this table. Filming amine usage should be restricted to injection over a period of several hours, in large steam distribution systems immediately before a seasonal shutdown. At plants with chronic condensate line corrosion control problems, satellite injection of
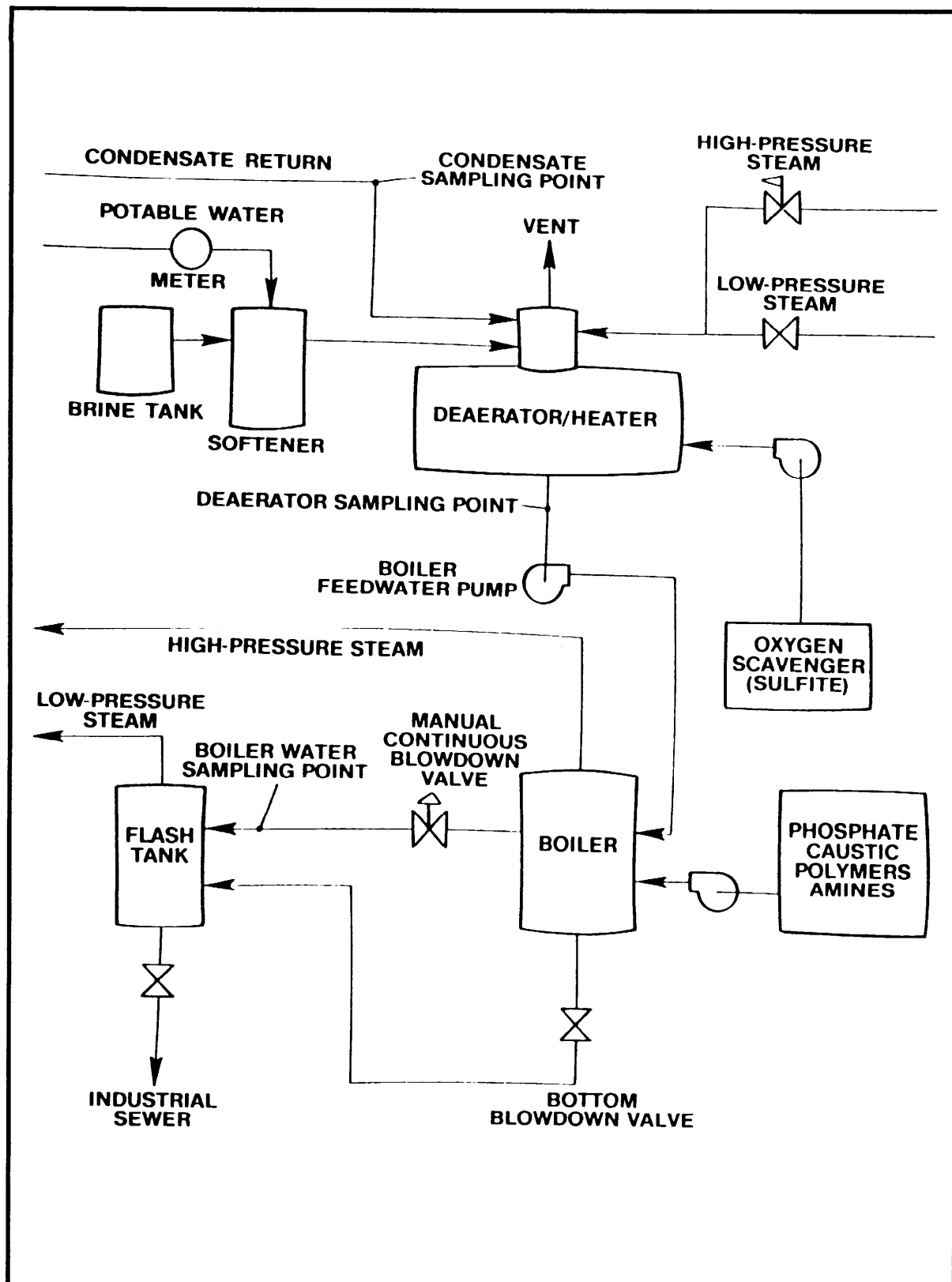
FIGURE C-2
Schematic of water treatment equipment at a large continuously manned boiler plant
with manual continuous blowdown

filming amines may be needed. However, such a decision should be made only after a comprehensive evaluation of the plant water treatment system is accomplished.

Chemical	Purpose
caustic soda	alkalinity control for boilers with dealkalizers
sodium sulfite with cobalt catalyst	O_2 scavenging
sodium hexametaphosphate	hardness control
neutralizing amine	condensate corrosion control
polymeric conditioner	sludge dispersant

C. Implementation

Public Works personnel have responsibility for implementing steam boiler water treatment programs. Public Works will maintain supplies of caustic soda, sodium sulfite with metal catalyst, and sodium hexametaphosphate. Boiler plant operations personnel are responsible for obtaining these chemicals and maintaining a sufficient stock of chemicals at their respective boiler plants for one to two months of operation.

This section presents the specific procedures for treating the water in a steam boiler. Each Bill of Attendance is presented on a separate page for case of copying them for the boiler rooms.

The following step-by-step procedures will be performed once per shift for each boiler at the plant.

Step No.	Description
1	On each boiler in operation, open the bottom blowdown valves according to the schedule in use at the plant. After some experience implementing the water treatment program, this schedule may be modified. However, any changes in bottom blowdown schedules must be approved by the boiler plant supervisor.
2	Turn on the cold water to the boiler water sample cooling coil. Open the specific boiler water line slowly until a steady stream of boiler water is flowing, free of sparging and flashing. Wait approximately two minutes. Slowly fill a clean sample container from the sample cooler, then close all valves.
3	Perform the following tests in order:

  * Conductivity (If conductivity exceeds limits, discard sample and repeat step #1 blowing down the mud drum until within limits.)

  * P Alkalinity (If P Alkalinity exceeds 600 ppm, discard sample and repeat step #1 blowing down the mud drum until within limits.)

  * Sulfite

* Phosphate

4   Take samples of condensate from the various condensate return lines where the condensate is free of make-up water addition,

5   Analyze the samples of condensate for pH.

6   Record results on water treatment log for each boiler and condensate loop. Use the example forms provided as pages B-2 and B-3 or similar forms. Calculate the required chemical quantities.

7   Mix the sodium sulfite in softened water, being careful not to aerate; add solution to the chemical feed tank supplying the deaerator and fill with softened water to produce the desired solution concentration. Change the pump stroke or pump speed to maintain the treatment limits.

* 8   Mix the powdered phosphate, liquid polymer and caustic flake with softened water in the proper chemical feed tank and fill with softened water. Adjust the pump stroke or speed to maintain the treatment limits.

9   Adjust the metering pump for the neutralizing amines being injected directly into the steam header.

10   Adjust the continuous blowdown metering valve to maintain the treatment limits. (At some pets this step may have to be accomplished more frequently.)

11   Record the quantities of chemicals added on a form similar to that provided as page B-4 of this document. The water treatment log should include comments or noted discrepancies. Particular attention must be given to changes of settings on the chemical feed pumps or to the continuous blowdown valves.

* If the boilers are not equipped with individual chemical feed tanks and pumps, the phosphate, caustic, and polymers are added into the boiler feedwater line servicing all of the boilers. The chemical parameters of each boiler should be considered and the chemical feed pump speed and/or stroke should be changed to maintain the minimum levels of phosphate and caustic in each of the boilers.

C-11

3. MEDIUM SIZE STEAM PLANTS, CONTINUOUSLY MANNED WITH AUTOMATIC BLOWDOWN CONTROLLERS.

A. Treatment Limits for Boilers Operating Below 300 psi

Boiler water will be treated to maintain the following limits:

Parameter	Limits
Alkalinity, Total	700 ppm maximum as $CaCO_3$
Alkalinity, P	250-600 ppm as $CaCO_3$
Conductivity	3,500 umhos/cm (neutralized)
Hardness	< 03 ppm as $CaCO_3$
pH	10.5-11.2
Phosphate	30-60 ppm as PO_4
Polymeric Dispersant	As directed by manufacturer (e.g. 1 quart added per thousand pounds of steam generated)
Sulfite	30-60 ppm as SO_3

Automatic conductivity controllers continuously monitor the conductivity of the boiler water. As the concentration of dissolved solids increases, the controller senses the corresponding increase in boiler water conductivity. The controller then increases the flow of blowdown from the continuous blowdown port. This causes an increase in makeup water to the boiler, dilutes the boiler water, and prevents scale formation.

Automatic controllers permit fairly high levels of dissolved solids in the boilers. However, they should be continually checked for accuracy of readings and recalibrated as necessary. A depiction of water treatment equipment for a medium boiler plant is provided as Figure C-3.

Produced steam should be chemically treated with neutralizing amines to maintain the pH of returning condensate between 7.5 and 8.5. A mixture of morpholine and cyclohexylamine is typically used for this purpose. Do not purchase these chemicals in concentrations greater than a 40 percent solution. Few power plant personnel have the necessary safety equipment to dilute these reagents from concentrated stocks. Also, avoid purchasing these chemicals in a solution strength less than 30 percent.

Boiler feedwater should be treated by mechanical deaeration in larger steam plants to maintain the dissolved oxygen at less than 0.05 ppm.

Evaluation of sulfite residual will not determine dissolved oxygen concentrations in a boiler. Further, samples of deaerated water must be taken without contamination by sulfite feed into the storage section of the deaerator/heater. For some units, the sulfite feed should be shut down for several hours before obtaining a sample for trace oxygen analysis.
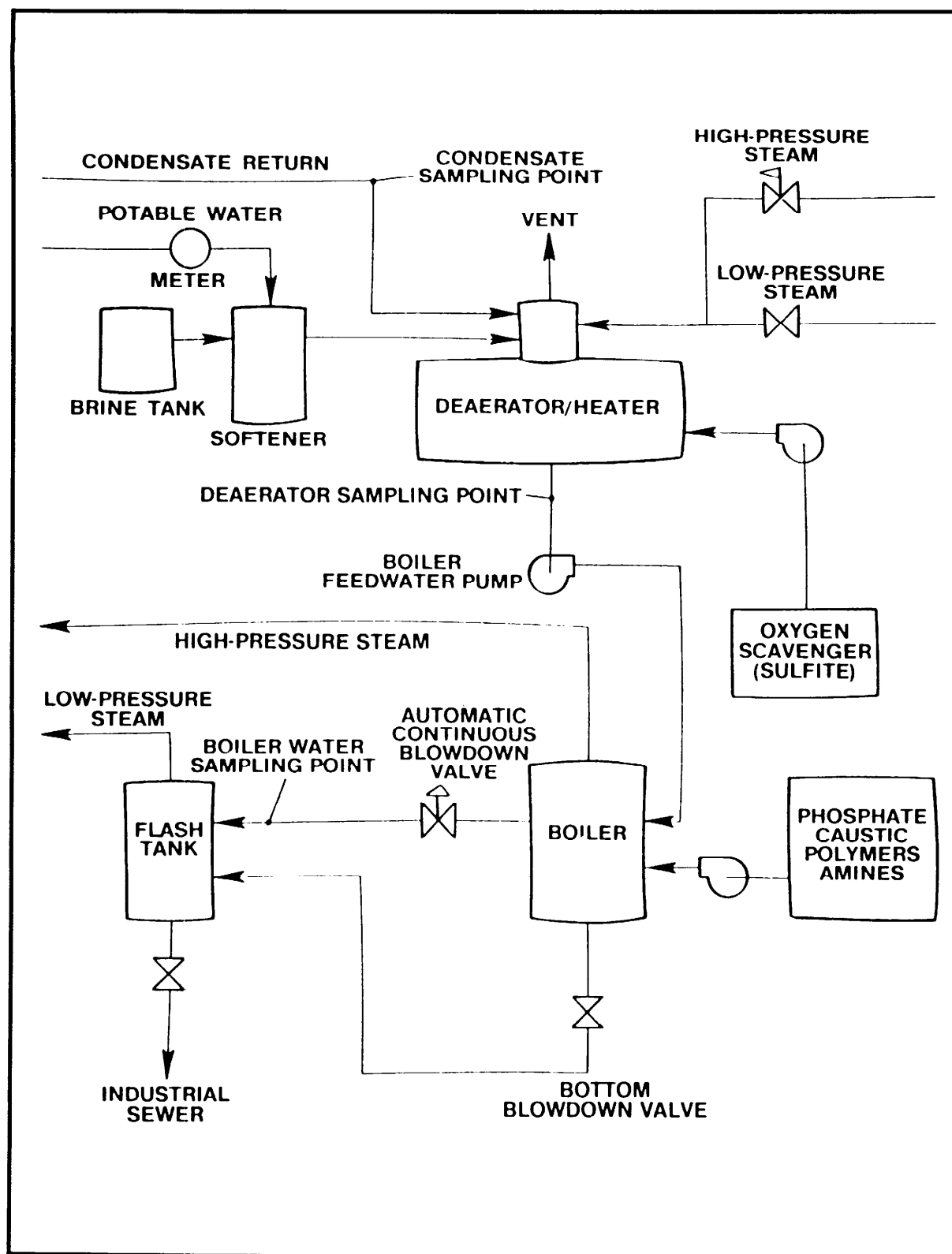
FIGURE C-3
Schematic of water treatment equipment at a medium size continuously manned
boiler plant with automatically controlled blowdown

C-13

B. Chemicals Required

The following table details the chemicals required to implement this program. Note that filming amines are not listed in this table. Filming amine use should be restricted to injection over a period of several hours, in large steam distribution systems immediately before a seasonal shut-down. At plants with chronic condensate line corrosion control problems, satellite injection of filming amines may be needed. However, such a decision should be made only after a comprehensive evaluation of the plant water treatment system is accomplished.

Chemical	Purpose
caustic soda	alkalinity control for boilers with dealkalizers
sodium sulfite with cobalt catalyst	O_2 scavenging
sodium hexametaphosphate	hardness control
neutralizing amine	condensate corrosion control
polymeric conditioner	sludge dispersant

C. Implementation

Public Works personnel have responsibility for implementing steam boiler water treatment programs. Public Works will maintain stocks of caustic soda, sodium sulfite with metal catalyst, and sodium hexametaphosphate. Boiler plant operations personnel are responsible for obtaining these chemicals and maintaining a sufficient stock of chemicals at their respective boiler plants for one to two months of operation.

This section presents the specific procedures for treating the water in a steam boiler. Each Bill of Attendance is presented on a separate page for ease of copying them for the boiler rooms.

The following step-by-step procedures will be performed once per shift for each boiler at the plant.

Step no.	Description
1	On each boiler in operation, open the bottom blowdown valves according to the schedule in use at the plant. After some experience implementing this water treatment program, the schedule may be modified. However, any changes in bottom blowdown schedules should be explicitly approved by the boiler plant supervisor.
2	Turn on the cold water to the boiler water sample cooling coil. Open the specific boiler water line slowly until a steady stream of boiler water is flowing, free of sparging and flashing. Wait approximately two minutes. Slowly fill a clean sample container from the sample cooler, then close all valves.
3	Perform the following tests in order: * Conductivity (If conductivity exceeds limits, discard sample and repeat step #1 blowing down the mud drum until within limits.) * P Alkalinity (If P Alkalinity exceeds 600 ppm, discard sample and repeat step #1

blowing down the mud drum until within limits.)
* Sulfite
* Phosphate

4   Take samples of condensate from the various condensate return lines where the condensate is free of make-up water addition.

5   Analyze the samples of condensate for pH.

6   Record results on water treatment log for each boiler and condensate loop. Use the example forms provided as pages B-2 and B-3 or similar forms. Calculate the required chemical quantities.

7   Mix the sodium sulfite in softened water, being careful not to aerate; add solution to the chemical feed tank supplying the deaerator and fill with softened water to produce the desired solution concentration. Change the pump stroke or pump speed to maintain the treatment limits.

* 8   Mix the powdered phosphate, liquid polymer, amine solution and caustic flake with softened water in the proper chemical feed tank and fill with softened water. Adjust the pump stroke or speed to maintain the treatment limits.

9   Adjust the automatic continuous blowdown controller setting to maintain the treatment limits. Once per week clean and calibrate the conductivity probes. (When the probe is found to be in excess of 200 micromhos in error, this calibration step may have to be accomplished more frequently.)

10   Record the quantities of chemicals added on a form similar to that provided as page B-4 of this document. The water treatment log should include comments or noted discrepancies. Particular attention must be given to changes of settings on the chemical feed pumps or to the automatic continuous blowdown controller.

*   If the boilers are not equipped with individual chemical feed tanks and pumps, the phosphate, caustic, and polymers are added into the boiler feedwater line servicing all of the boilers. The chemical parameters of each boiler must be considered and the chemical feed pump speed and/or stroke must be changed to maintain the minimum levels of phosphate and caustic in each of the boilers. Consideration should be given to the installation of an additional chemical feed pump for the neutralizing amines since it will be quite difficult to balance the pH of the returning condensate. The optimum location for injection of the amines is into the steam header departing the power plant.

*   If the facility is not equipped with an individual tank and pump for sulfite, the existing tank should be returned to use for feeding sulfite after each boiler is isolated and treated separately. An adjustment is then needed for Steps 7 and 8 as follows:

7   Dilute the phosphate, polymer, and amines in softened water; add to the chemical feed tank and fill with softened water. Pump the chemical feed tank dry; flush with softened water and pump the tank empty.

8   Dilute the sodium sulfite in softened water or condensate, being careful not to over-aerate; add to the chemical feed tank and fill with softened water to produce the desired solution concentration. Adjust the pump stroke or pump speed to maintain treatment limits.

4. MEDIUM SIZE STEAM PLANTS, CONTINUOUSLY MANNED WITH MANUAL CONTINUOUS BLOWDOWN CONTROLS.

A. Treatment Limits for Boilers Operating Below 300 psi

Boiler water will be treated to maintain the following limits:

Parameter	Limits
Alkalinity, Total	700 ppm maximum as $CaCO_3$
Alkalinity, P	250-600 ppm as $CaCO_3$
Conductivity	3,000 umhos/cm (neutralized)
Hardness	< 0.3 ppm as $CaCO_3$
pH	10.5-11.2
Phosphate	30-60 ppm as PO_4
Polymeric Dispersant	As directed by manufacturer (e.g. 1 quart added per thousand pounds of steam generated)
Sulfite	30-60 ppm as SO_3

Manual continuous blowdown valves permit higher levels of dissolved solids in the boilers than possible with bottom blowdown alone. However, the settings of these valves must be continually checked. Changes in makeup or condensate return rates will significantly influence the dissolved solids level in the boiler equipped with a fixed setting on the continuous blowdown valve. A depiction of water treatment equipment for a medium size steam boiler plant is provided as Figure C-4.

Produced steam should be chemically treated with neutralizing amines to maintain the pH of returning condensate between 7.5 and 8.5. A mixture of morpholine and cyclohexylamine is typically used for this purpose. Do not purchase these chemicals in concentrations greater than a 40 percent solution. Few power plant personnel have the necessary safety equipment to dilute these reagents from concentrated stocks. Also, avoid purchasing these chemicals in a solution strength less than 30 percent.

Boiler feedwater should be treated by mechanical deaeration in larger steam plants to maintain the dissolved oxygen at less than 0.05 ppm.

Evaluation of sulfite residual will not determine dissolved oxygen concentrations in a boiler. Further, samples of deaerated water should be taken without contamination by sulfite feed into the storage section of the deaerator/heater. For some units, the sulfite feed should be shut down for several hours before obtaining a sample for trace oxygen analysis.

B. Chemicals Required

The following table details the chemicals required to implement this program. Note that filming amines are not listed in this table. Filming amine use should be restricted to injection over a period of several hours, in large steam distribution systems immediately before a seasonal shut-down At plants with chronic condensate line corrosion control problems, satellite injection of
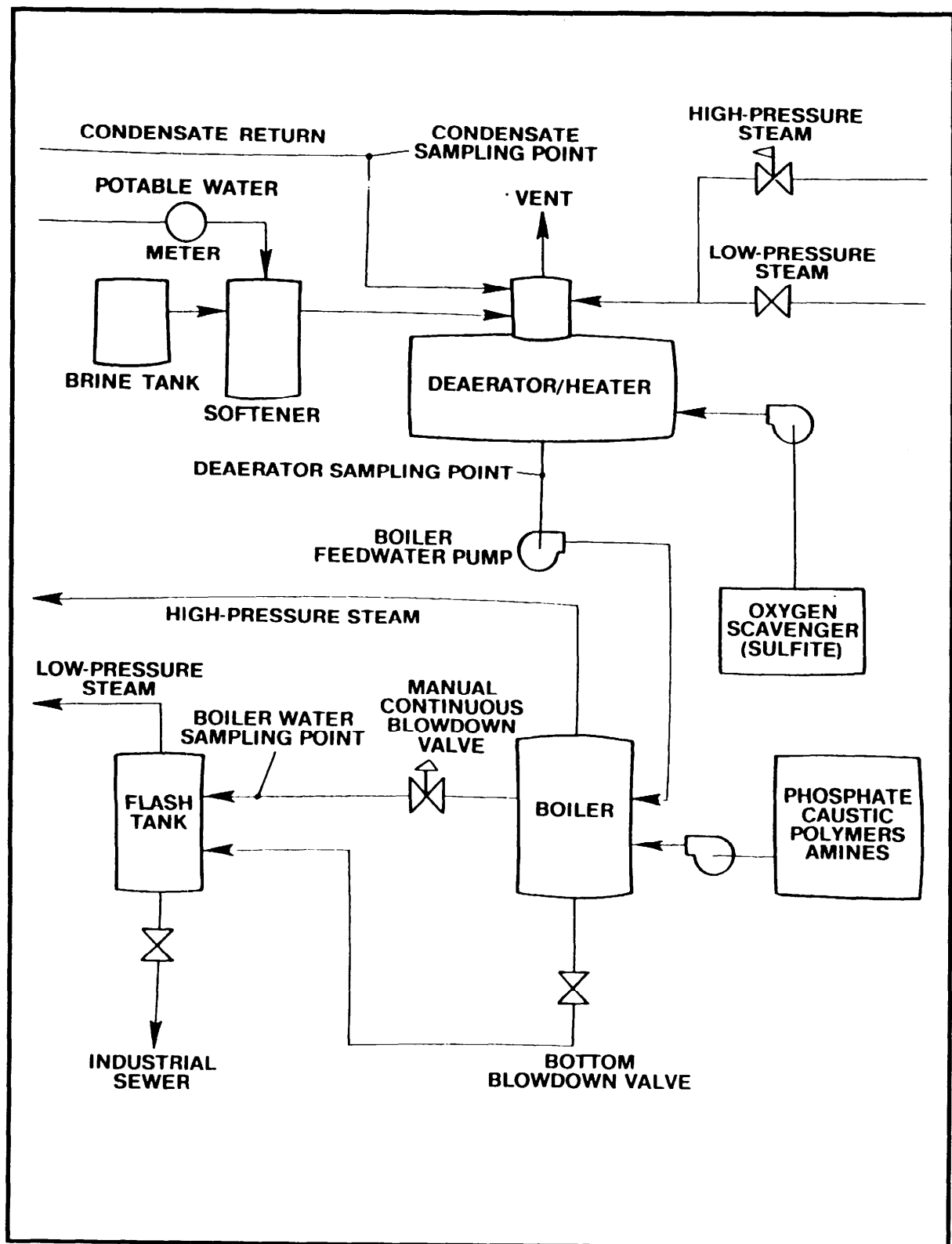
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FIGURE C-4
Schematic of water treatment equipment at a medium size continuously manned
boiler plant with manual continuous blowdown valves

filming amines may be needed. However, such a decision should be made only after a comprehensive evaluation of the plant water treatment system is accomplished.

Chemical	Purpose
caustic soda	alkalinity control for boilers with dealkalizers
sodium sulfite with cobalt catalyst	O_2 scavenging
sodium hexametaphosphate	hardness control
neutralizing amine	condensate corrosion control
polymeric conditioner	sludge dispersant

C. Implementation

Public Works personnel have responsibility for implementing steam boiler water treatment programs. Public Works will maintain supplies of caustic soda, sodium sulfite with metal catalyst, and sodium hexametaphosphate. Boiler plant operations personnel are responsible for obtaining these chemicals and maintaining a sufficient stock of chemicals at their respective boiler plants for one to two months of operation.

This section presents the specific procedures for treating the water in a steam boiler. Each Bill of Attendance is presented on a separate page for ease of copying these procedures for the boiler rooms.

The following step-by-step procedures will be performed once per shift for each boiler at the plant.

Step No.	Description
1	On each boiler in operation, open the bottom blowdown valves according to the schedule in use at the plant. After some experience implementing this water treatment program, the schedule may be modified. However, any changes in bottom blowdown schedules should be explicitly approved by the boiler plant supervisor.
2	Turn on the cold water to the boiler water sample cooling coil. Open the specific boiler water line slowly until a steady stream of boiler water is flowing, free of sparging and flashing. Wait approximately two minutes. slowly fill a clean sample container from the sample cooler, then dose all valves.
3	Perform the following tests in order: * Conductivity (If conductivity exceeds limits, discard sample and repeat step #1 blowing down the mud drum until within limits.) * P Alkalinity (If P Alkalinity exceeds 600 ppm, discard sample and repeat step #1 blowing down the mud drum until within limits.) * Sulfite * Phosphate
4	Take samples of condensate from the various condensate return lines where the condensate is free of make-up water addition.
5	Analyze the samples of condensate for pH.

6   Record results on water treatment log for each boiler and condensate loop. Use the example forms provided as pages B-2 and B-3 or similar forms. Calculate the required chemical quantities.

7   Mix the sodium sulfite in softened water, being careful not to aerate; add solution to the chemical feed tank supplying the deaerator and fill with softened water to produce the desired solution concentration. Change the pump stroke or pump speed to maintain the treatment limits.

* 8   Mix the powdered phosphate, liquid polymer, amine solution and caustic flake with softened water in the proper chemical feed tank and fill with softened water. Adjust the pump stroke or speed to maintain the treatment limits.

9   Adjust the setting on the manual continuous blowdown control to maintain the treatment limits. (At some plants this adjustment step may have to be accomplished on a more frequent basis.)

10   Record the quantities of chemicals added on a form similar to that provided as page B-4 of this document. The water treatment log should include any comments or noted discrepancies. Particular attention should be given to changes of settings on chemical feed pumps or to the manual continuous blowdown control valves.

*   If the boilers are not equipped with individual chemical feed tanks and pumps, the phosphate, caustic, and polymers are added into the boiler feedwater line servicing all of the boilers. The chemical parameters of each boiler should be considered and the chemical feed pump speed and/or stroke should be changed to maintain the minimum levels of phosphate and caustic in each of the boilers. Consideration should be given to the installation of an additional chemical feed pump for the neutralizing amines since it will be quite difficult to balance the pH of the returning condensate. The optimum location for injection of the amines is into he steam header departing the power plant.

*   If the facility is not equipped with an individual tank and pump for sulfite, the existing tank should be returned to use for feeding sulfite after each boiler is isolated and treated separately. An adjustment is then needed for Steps 7 and 8 as follows:

7   Dilute the phosphate, polymer, and amines in softened water; add to the chemical feed tank and fill with softened water. Pump the chemical feed tank dry; flush with softened water and pump the tank empty.

8   Dilute the sodium sulfite in softened water or condensate, being careful not to over-aerate; add to the chemical feed tank and fill with softened water to produce the desired solution concentration. Adjust the pump stroke or pump speed to maintain the treatment limits.

5. MEDIUM SIZE STEAM PLANTS, SEASONALLY MANNED WITH AUTOMATIC BLOWDOWN CONTROLLERS.

A. Treatment Units for Boilers Operating Below 300 psi.

Boiler water will be treated to maintain the following limits:

Parameter	Limits
Alkalinity, Total	700 ppm maximum as $CaCO_3$
Alkalinity, P	250-600 ppm as $CaCO_3$
Conductivity	3,500 umhos/cm (neutralized)
Hardness	< 0.3 ppm as $CaCO_3$
pH	10.5-11.2
Phosphate	30-60 ppm as PO_4
Polymeric Dispersant	As directed by manufacturer (e.g. 1 quart added per thousand pounds of steam generated)
Sulfite	30-60 ppm as SO_3

Automatic conductivity controllers continuously monitor the conductivity of the boiler water. As the concentration of dissolved solids increases, the controller senses the corresponding increase in boiler water conductivity. The controller then increases the flow of blowdown from the continuous blowdown port. This causes an increase in makeup water to the boiler to dilute the boiler water and prevent scale formation.

These automatic controllers permit fairly high levels of dissolved solids in the boilers. However, they should be continually checked for accuracy of readings and recalibrated as necessary. A depiction of water treatment equipment for a medium size steam boiler plant is provided as Figure C-5.

Produced steam should be chemically treated with neutralizing amines to maintain the pH of returning condensate between 7.5 and 8.5. A mixture of morpholine and cyclohexylamine is typically used for this purpose. Do not purchase these chemicals in concentrations greater than a 40 percent solution. Few power plant personnel have the necessary safety equipment to dilute these reagents from concentrated stocks. Also, avoid purchasing these chemicals in a solution strength less than 30 percent.

Boiler feedwater should be treated by mechanical deaeration in larger steam plants to maintain the dissolved oxygen at less than 0.05 ppm.

Evaluation of sulfite residual will not determine dissolved oxygen concentrations in a boiler. Further, samples of deaerated water should be taken without contamination by sulfite feed into the storage section of the deaerator/heater. For some units, the sulfite feed should be shut down for several hours before obtaining a sample for trace oxygen analysis.
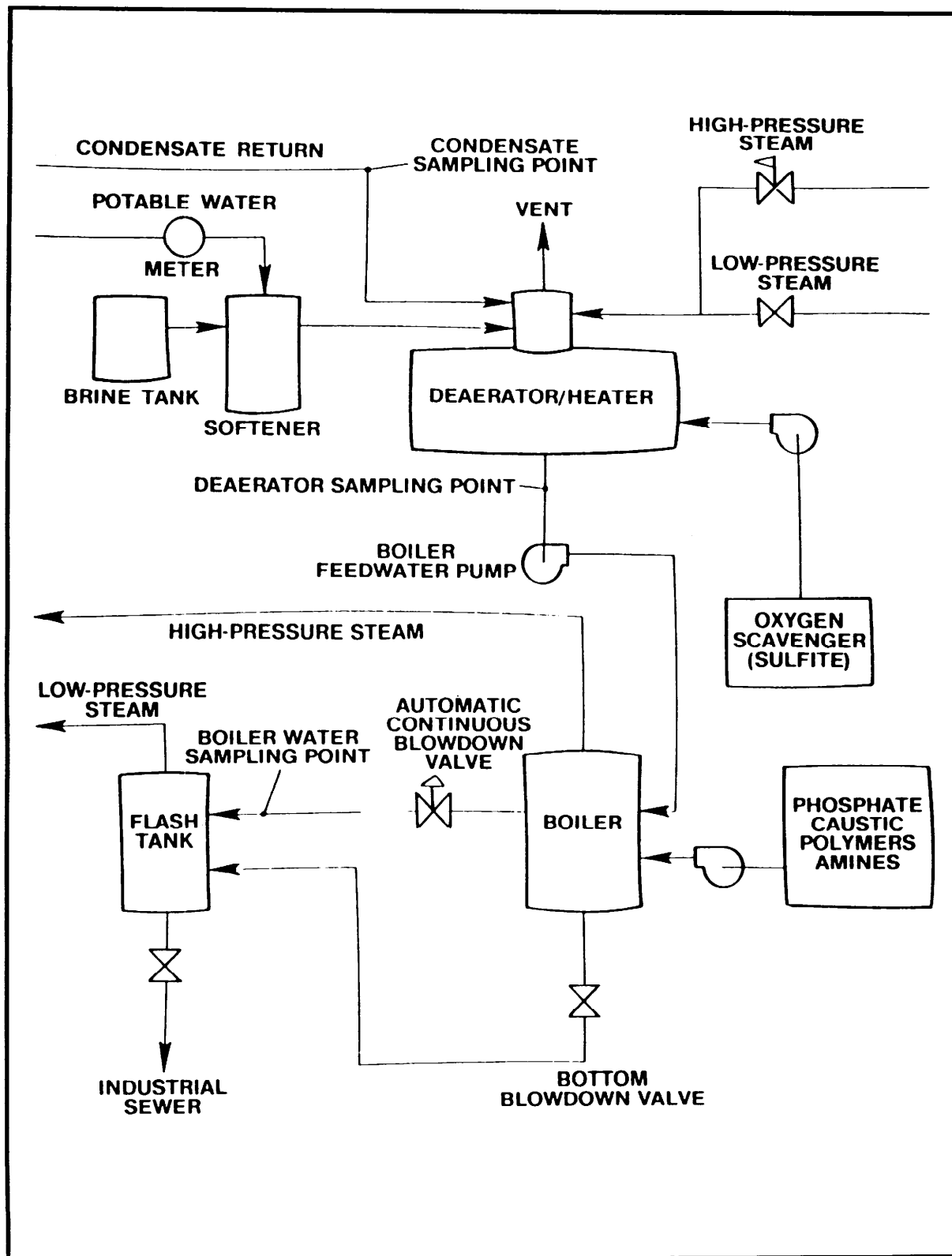
FIGURE C-5

Schematic of water treatment equipment at a medium size seasonally manned boiler plant with automatically controlled blowdown

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B. Chemicals Required

The following table details the chemicals required to implement this program. Note that filming amines are not listed in this table. Filming amine use should be restricted to injection over a period of several hours, in large steam distribution systems immediately before a seasonal shut-down. At plants with chronic condensate line corrosion control problems, satellite injection of filming amines may be needed. However, such a decision should be made only after a comprehensive evaluation of the plant water treatment system is accomplished.

Chemical	Purpose
caustic soda	alkalinity control for boilers with dealkalizers
sodium sulfite with cobalt catalyst	O_2 scavenging
sodium hexametaphosphate	hardness control
neutralizing amine	condensate corrosion control
polymeric conditioner	sludge dispersant

C. Implementation

Public Works personnel have responsibility for implementing steam boiler water treatment programs. Public Works will maintain stocks of caustic soda, sodium sulfite with metal catalyst, and sodium hexametaphosphate. Boiler plant operations personnel are responsible for obtaining these chemicals and maintaining a sufficient stock of chemicals at their respective boiler plants for one to two months of operation.

This section presents the specific procedures for treating the water in a steam boiler. Each Bill of Attendance is presented on a separate page for ease of copying them for the boiler rooms.

The following step-by-step procedures will be performed once per shift for each boiler at the plant.

Step No.	Description
1	On each boiler in operation, open the bottom blowdown valves according to the schedule in use at the plant. After some experience implementing this water treatment program, the schedule may be modified. However, any changes in bottom blowdown schedules should be explicitly approved by the boiler plant supervisor.
2	Turn on the cold water to the boiler water sample cooling coil. Open the specific boiler water line slowly until a steady stream of boiler water is flowing, free of sparging and flashing. Wait approximately two minutes. Slowly fill a clean sample container from the sample cooler, then close all valves.

3   Perform the following tests in order:

* Conductivity (If conductivity exceeds limits, discard sample and repeat step #1 blowing down the mud drum until within limits.)

* P Alkalinity (If P Alkalinity exceeds 600 ppm, discard sample and repeat step #1 blowing down the mud drum until within limits.)

* sulfite

* Phosphate

4   Take samples of condensate from the various condensate return lines where the condensate is free of make-up water addition.

5   Analyze. the samples of condensate for pH.

6   Record results on water treatment log for each boiler and condensate loop. Use the example forms provided as pages B-2 and B-3 or similar forms. Calculate the required chemical quantities.

7   Mix the sodium sulfite in softened water, being careful not to aerate; add solution to the chemical feed tank supplying the deaerator and fill with softened water to produce the desired solution concentration. Change the pump stroke or pump speed to maintain the treatment limits.

* 8   Mix the powdered phosphate, liquid polymer, amine solution and caustic flake with softened water in the proper chemical feed tank and fill with softened water. Adjust the pump stroke or speed to maintain the treatment limits.

9   Adjust the automatic continuous blowdown controller setting to maintain the treatment limits. Once per week clean and calibrate the conductivity probes. (When the probe is found to be in excess of 200 micromhos in error, this calibration step may have to be accomplished more frequently.)

10   Record the quantities of chemicals added on a form similar to that provided as page B-4 of this document. The water treatment log should include any comments or noted discrepancies. Particular attention should be given to changes of settings on chemical feed pumps or to the automatic continuous blowdown controller.

*   If the boilers are not equipped with individual chemical feed tanks and pumps, the phosphate, caustic, and polymers are added into the boiler feedwater line servicing all of the boilers. The chemical parameters of each boiler should be considered and the chemical feed pump speed and/or stroke should be changed to maintain the minimum levels of phosphate and caustic in each of the boilers. Consideration should be given to the installation of an additional chemical feed pump for the neutralizing amines since it will be quite difficult to balance the pH of the returning condensate. The optimum location for injection of the neutralizing amines is into the steam header departing the power plant.

*   If the facility is not equipped with an individual tank and pump for sulfite, the existing tank should be returned to use for feeding sulfite after each boiler is isolated and treated separately. An adjustment is then needed for Steps 7 and 8 as follows:

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7   Dilute the phosphate, polymer, and amines in softened water; add to the chemical feed
     tank and fill with softened water. Pump the chemical feed tank dry; flush with softened
     water and pump the tank empty.

8   Dilute the sodium sulfite in softened water or condensate, being careful not to over-aerate;
     add to the chemical feed tank and fill with softened water to produce the desired solution
     concentration. Adjust the pump stroke or pump speed to maintain the treatment limits.

6. MEDIUM SIZE STEAM PLANTS, SEASONALLY MANNED WITH MANUAL CONTINUOUS BLOWDOWN CONTROLLERS.

A. Treatment Limits for Boilers Operating Below 300 psi

Boiler water will be treated to maintain the following limits:

Parameter	Limits
Alkalinity, Total	700 ppm maximum as $CaCO_3$
Akalinity, P	250-600 ppm as $CaCO_3$
Conductivity	3,000 umhos/cm (neutralized)
Hardness	< 0.3 ppm as $CaCO_3$
pH	10.5-11.2
Phosphate	30-60 ppm as PO_4
Polymeric Dispersant	As directed by manufacturer (eg. 1 quart added per thousand pounds of steam generated)
Sulfite	30-60 ppm as SO_3

Manual continuous blowdown valves permit higher levels of dissolved solids in the boilers than with bottom blowdown alone. However, valve settings should be continually checked Changes in makeup or condensate return rates significantly influence the dissolved solids level in boilers with a fixed setting on the continuous blowdown valve. A depiction of water treatment equipment for a medium size boiler plant is provided as Figure C-6.

Produced steam should be chemically treated with neutralizing amines to maintain the pH of returning condensate between 7.5 and 8.5. A mixture of morpholine and cyclohexylamine is typically used for this purpose. Do not purchase these chemicals in concentrations greater than a 40 percent solution. Few power plant personnel have the necessary safety equipment to dilute these reagents from concentrated stocks. Also, avoid purchasing these chemicals in a solution strength less than 30 percent.

B. Chemicals Required

The following table details the chemicals required to implement this program. Note that filming amines are not listed in this table. Filming amine use should be restricted to injection over a period of several hours in large steam distribution systems immediately before seasonal shutdown. At plants with chronic condensate line corrosion control problems, satellite injection of filming amines may be needed. However, such a decision should be made only after a comprehensive evaluation of the plant water treatment system is accomplished.

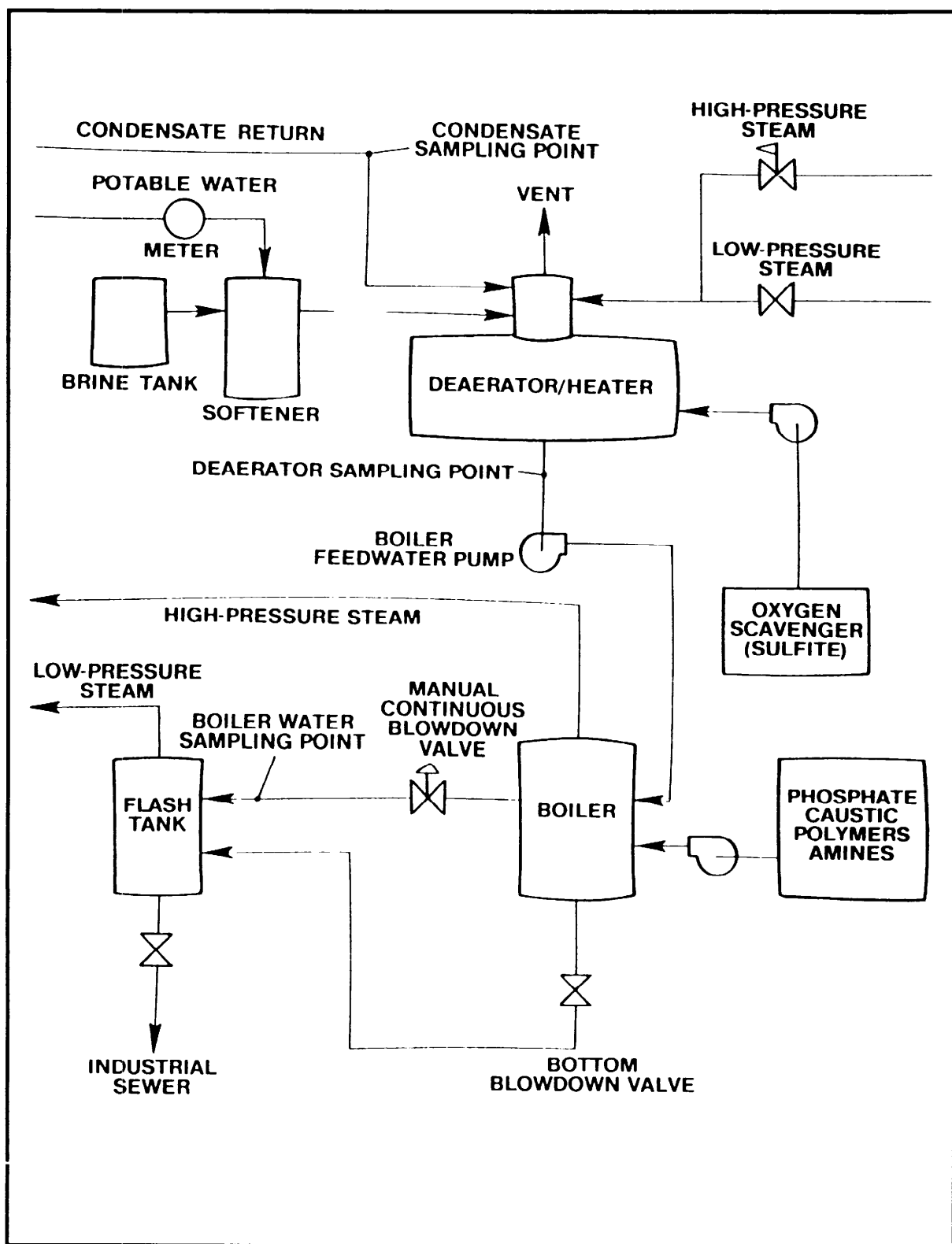| Chemical	Purpose
caustic soda	alkalinity control for boilers with dealkalizers

FIGURE C-6

Schematic of water treatment equipment at a medium size seasonally manned
boiler plant with manual continuous blowdown valves

sodium sulfite with cobalt catalyst	O_2 scavenging
sodium hexametaphosphate	hardness control
neutralizing amine	condensate corrosion control
polymeric conditioner	sludge dispersant

C. Implementation

Public Works personnel have responsibility for implementing steam boiler water treatment programs. Public Works will maintain supplies of caustic soda, sodium sulfite with metal catalyst, and sodium hexametaphosphate. Boiler plant operations personnel are responsible for obtaining these chemicals and maintaining a sufficient stock of chemicals at their respective boiler plants for one to two months of operation.

This section presents the specific procedures for treating the water in a steam boiler. Each Bill of Attendance is presented on a separate page for ease of copying them for the boiler rooms.

The following step-by-step procedures will be performed once per shift for each boiler at the plant.

Step No.   **Description**

1   On each boiler in operation, open the bottom blowdown valves according to the schedule
     in use at the plant. After some experience implementing this water treatment program, the
     schedule may be modified. However, any changes in bottom blowdown schedules should be
     explicitly approved by the boiler plant supervisor.

2   Turn on the cold water to the boiler water sample cooling coil. Open the specific boiler
     water line slowly until a steady stream of boiler water is flowing, free of sparging and
     flashing. Wait approximately two minutes. Slowly fill a clean sample container from the
     sample cooler, then close all valves. (Note: On low pressure boilers, samples of boiler
     water can frequently be obtained from site glass drains with only minimal flashing. Care
     should be taken in obtaining a sample in this manner due to the scalding nature of the
     boiler water and the potential of live steam purging through the site glass.)

3   Perform the following tests in order:

     * Conductivity (If conductivity exceeds limits, discard sample and repeat step #1 blowing
     down the mud drum until within limits.)

     * P Alkalinity (If P Alkalinity exceeds 600 ppm, discard sample and repeat step #1
     blowing down the mud drum until within limits.)

     * Sulfite

     * Phosphate

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4   Take samples of condensate from the various condensate return lines where the condensate is free of make-up water addition.

5   Analyze the samples of condensate for pH.

6   Record results on water treatment log for each boiler and condensate loop. Use the example forms provided as pages B-2 and B-3 or similar forms. Calculate the required chemical quantities.

* 7   Mix the powdered phosphate, powdered sulfite, liquid polymer, amine solution and caustic flake with softened water in
        the proper chemical feed tank and fill with softened water. Adjust the pump stroke or speed to maintain the treatment limits.

8   Adjust the setting on the manual continuous blowdown control to maintain the treatment limits. (At some plants this adjustment step may have to be accomplished on a more frequent basis.)

9   Record the quantities of chemicals added on a form similar to that provided as page B-4 of this document. The water treatment log should include any comments or noted discrepancies. Particular attention should be given to changes of settings on chemical feed pumps or to the manual continuous blowdown control valves.

*   If the boilers are not equipped with individual chemical feed tanks and pumps, the sulfite, phosphate, caustic, and polymers are added into the boiler feedwater line servicing all of the boilers. The chemical parameters of each boiler should be considered and the chemical feed pump speed and/or stroke should be changed to maintain the minimum levels of phosphate and caustic in each of the boilers. Consideration should be given to the installation of an additional chemical feed pump for the neutralizing amines since it will be quite difficult to balance the pH of the returning condensate. The optimum location for injection of the amines is into the steam header departing the power plant.

*   If the facility is not equipped with an individual tank and pump for sulfite, the existing tank should be returned to use for feeding sulfite after each boiler is isolated and treated separately. An adjustment is then needed for Step 7 as follows:

7   Dilute the phosphate, polymer, and amines in softened water; add to the chemical feed tank and fill with softened water. Pump the chemical feed tank dry, flush with softened water and pump the tank empty.

7A   Dilute the sodium sulfite in softened water or condensate, being careful not to over-aerate; add to the chemical feed tank and fill with softened water to produce the desired solution concentration. Adjust the pump stroke or pump speed to maintain the treatment limits.

7. MEDIUM SIZE STEAM PUNTS, SEASONALLY MANNED WITH MANUAL BLOWDOWN CONTROLS.

A. Treatment Limits for Boilers Operating Below 300 psi

Boiler water will be treated to maintain the following limits:

Parameter	Limits
Alkalinity, Total	700 ppm maximum as $CaCO_3$
Alkalinity, P	250-600 ppm as $CaCO_3$
Conductivity	2,500 umhos/cm (neutralized)
Hardness	< 0.3 ppm as $CaCO_3$
pH	10.5-11.2
Phosphate	30-60 ppm as PO_4
Polymeric Dispersant	As directed by manufacturer (e.g. 1 quart added per thousand pounds of steam generated)
Sulfite	30-60 ppm as SO_3

Manual continuous blowdown valves permit higher levels of dissolved solids in the boilers than with bottom blowdown alone. However, valve settings should be continually checked. Changes in makeup or condensate return rates significantly influence the dissolved solids level in boilers with a fixed setting on the continuous blowdown valve. A depiction of water treatment equipment for a medium size boiler plant is provided as Figure C-7.

Produced steam should be chemically treated with neutralizing amines to maintain the pH of returning condensate between 7.5 and 8.5. A mixture of morpholine and cyclohexylamine is typically used for this purpose. Do not purchase these chemicals in concentrations greater than a 40 percent solution. Few power plant personnel have the necessary safety equipment to dilute these reagents from concentrated stocks. Also, avoid purchasing these chemicals in a solution strength less than 30 percent.

B. Chemicals Required

The following table details the chemicals required to implement this program. Note that the filming amines are not listed in this table. Filming amine use should be restricted to injection over a period of several hours in large steam distribution systems immediately before seasonal shutdown. At plants with chronic condensate line corrosion control problems, satellite injection of filming amines may be needed. However, such a decision should be made only after a comprehensive evaluation of the plant water treatment system is accomplished.
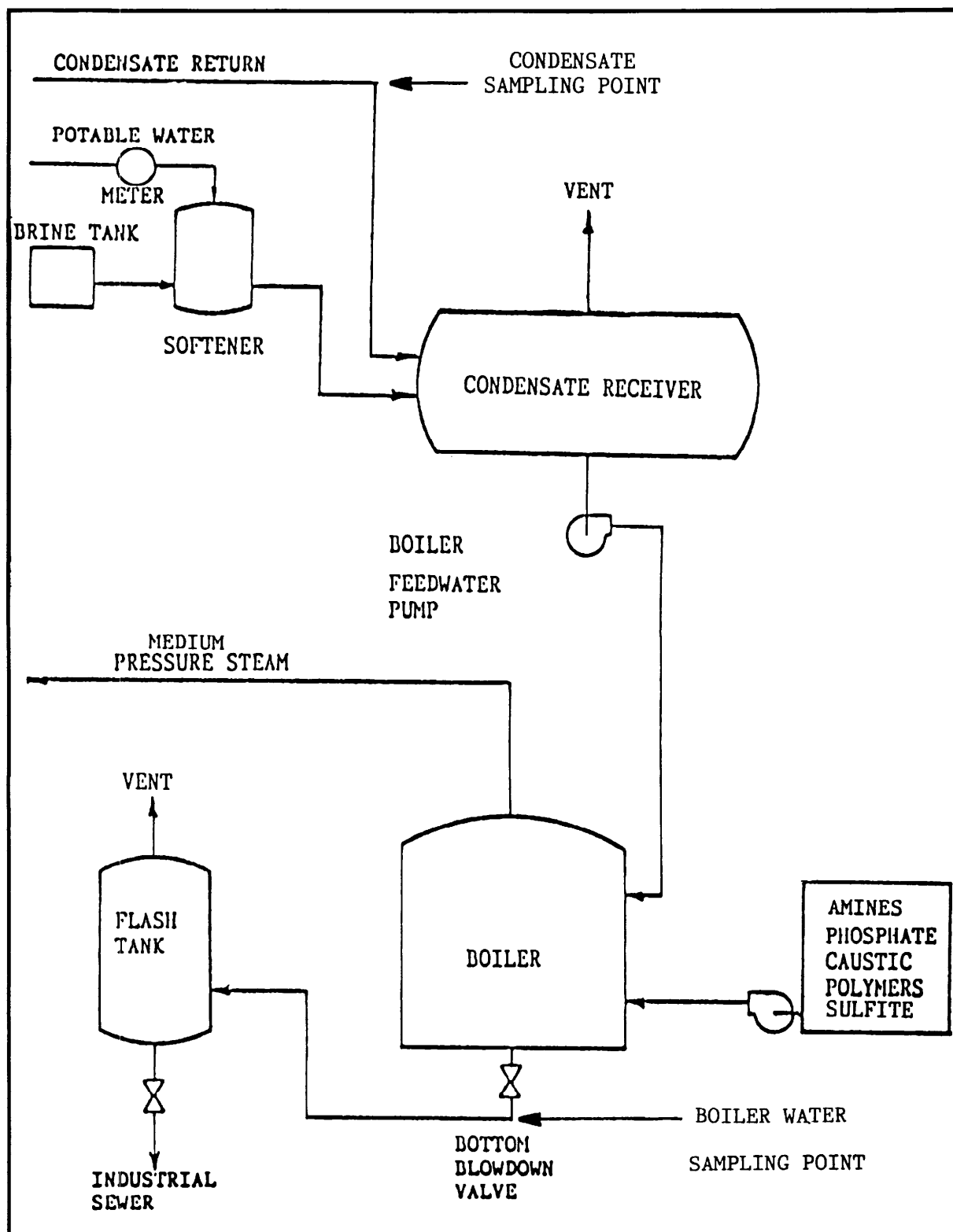
FIGURE C-7
Schematic of water treatment equipment at a medium size seasonally manned boiler plant equipped with bottom blowdown valves

Chemical	Purpose
caustic soda	alkalinity control for boilers with dealkalizers
sodium sulfite with cobalt catalyst	O_2 scavenging
sodium hexametaphosphate	hardness control
neutralizing amine	condensate corrosion control
polymeric conditioner	sludge dispersant

C. Implementation

Public Works personnel have responsibility for implementing steam boiler water treatment programs. Public Works will maintain supplies of caustic soda, sodium sulfite with metal catalyst, and sodium hexametaphosphate. Boiler plant operations personnel are responsible for obtaining these chemicals and maintaining a sufficient stock of chemicals at their respective boiler plants for one to two months of operation.

This section presents the specific procedures for treating the water in a steam boiler. Each Bill of Attendance is presented on a separate page for ease of copying them for the boiler rooms.

The following step-by-step procedures will be performed once per shift for each boiler at the plant.

Step No.	Description
1	On each boiler in operation, open the bottom blowdown valves according to the schedule in use at the plant. After some experience implementing this water treatment program, the schedule may be modified. However, any changes in bottom blowdown schedules should be explicitly approved by the boiler plant supervisor.
2	Turn on the cold water to the boiler water sample cooling coil. Open the specific boiler water line slowly until a steady stream of boiler water is flowing, free of sparging and flashing. Wait approximately two minutes. Slowly fill a clean sample container from the sample cooler, then close all valves. (Note: On low pressure boilers, samples of boiler water can frequently be obtained from site glass drains with only minimal flashing. Care should be taken in obtaining a sample in this manner due to the scalding nature of the boiler water and the potential of live steam purging through the site glass.)
3	Perform the following tests in order: * Conductivity (If conductivity exceeds limits, discard sample and repeat step #1 blowing down the mud drum until within limits.) * P Alkalinity (If P Alkalinity exceeds 600 ppm, discard sample and repeat step #1 blowing down the mud drum until within limits.) * Sulfite

*　Phosphate

4　　Take samples of condensate from the various condensate return lines where the condensate is free of make-up water addition.

5　　Analyze the samples of condensate for pH.

6　　Record results on water treatment log for each boiler and condensate loop. Use the example forms provided as pages B-2 and B-3 or similar forms. Calculate the required chemical quantities.

* 7　Mix the powdered phosphate, powdered sulfite, liquid polymer, amine solution, and caustic flake with softened water in the proper chemical feed tank and fill with softened water. Adjust the pump stroke or speed to maintain the treatment limits.

8　　Record the quantities of chemicals added on a form similar to that provided as page B-4 of this document. The water treatment log should include any comments or noted discrepancies. Particular attention should be given to changes of settings on chemical feed pumps or to the manual continuous blowdown control valves.

*　　If the boilers are not equipped with individual chemical feed tanks and pumps, the sulfite, phosphate, caustic, and polymers are added into the boiler feedwater line servicing all of the boilers. The chemical parameters of each boiler should be considered and the chemical feed pump speed and/or stroke should be changed to maintain the minimum levels of phosphate and caustic in each of the boilers. Consideration should be given to the installation of an additional chemical feed pump for the neutralizing amines since it will be quite difficult to balance the pH of the returning condensate. The optimum location for injection of the amines is into the steam header departing the power plant.

*　　If the facility is not equipped with an individual tank and pump for sulfite, the existing tank should be returned to use for feeding sulfite after each boiler is isolated and treated separately. An adjustment is then needed for Step 7 as follows:

7　　Dilute the phosphate, polymer, and amines in softened water; add to the chemical feed tank and fill with softened water. Pump the chemical feed tank dry; flush with softened water and pump the tank empty.

7A　A Dilute the sodium sulfite in softened water or condensate, being careful not to over-aerate; add to the chemical feed tank and fill with softened water to produce the desired solution concentration. Adjust the pump stroke or pump speed to maintain the treatment limits.

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8. SMALL SIZE STEAM PLANTS, UNMANNED WITH AUTOMATIC BLOW DOWN CONTROLLERS.

A. Treatment Limits with Boilers Operating Below 300 psi.

Boiler water will be treated to maintain the following limits:

Parameter	Limits
Alkalinity, Total	700 ppm maximum as $CaCO_3$
Alkalinity, P	250-600 ppm as $CaCO_3$
Conductivity	3,000 umhos/cm (neutralized)
Hardness	< 0.3 ppm as $CaCO_3$
pH	10.5-11.2
Phosphate	40-70 ppm as PO_4
Polymeric Dispersant	As directed by manufacturer (e.g. 1 quart added per thousand Pounds of steam generated)
Sulfite	40-70 ppm as SO_3

Automatic conductivity eontrollers continuously monitor the conductivity of the boiler water. As the concentration of dissolved solids increases, the controller senses the corresponding increase in boiler water conductivity. The controller then increases the flow of blowdown from the continuous blowdown port. This causes an increase in makeup water to the boiler to dilute the boiler water and prevent scale formation.

Automatic controllers Permit fairly high levels of dissolved solids in the boilers. However, they should be continually checked for accuracy of readings and recalibrated as necessary. A depiction of water treatment equipment for a small size steam boiler plant is provided in Figure C-8.

Produced steam should be chemically treated with neutralizing amines to maintain the pH of returning condensate between 7.5 and 8.5. A mixture of morpholine and cyclohexylamine is typically used for this purpose. Do not purchase these chemicals in concentrations greater than a 40 percent solution. Few Power plant Personnel have the necessary safety equipment to dilute these reagents from concentrated stocks. Also, avoid purchasing these chemicals in a solution strength less than 30 percent.

B. Chemicals Required

The following table details the chemicals required to implement this program. Note that filming amines are not listed in this table. Filming amine use should be restricted to injection over a Period of several hours in large steam distribution systems immediately before seasonal shutdown. At plants with chronic condensate line corrosion control problems, satellite injection of filming amines may be needed. However, such a decision should be made only after a comprehensive evaluation of the plant water treatment system is accomplished.
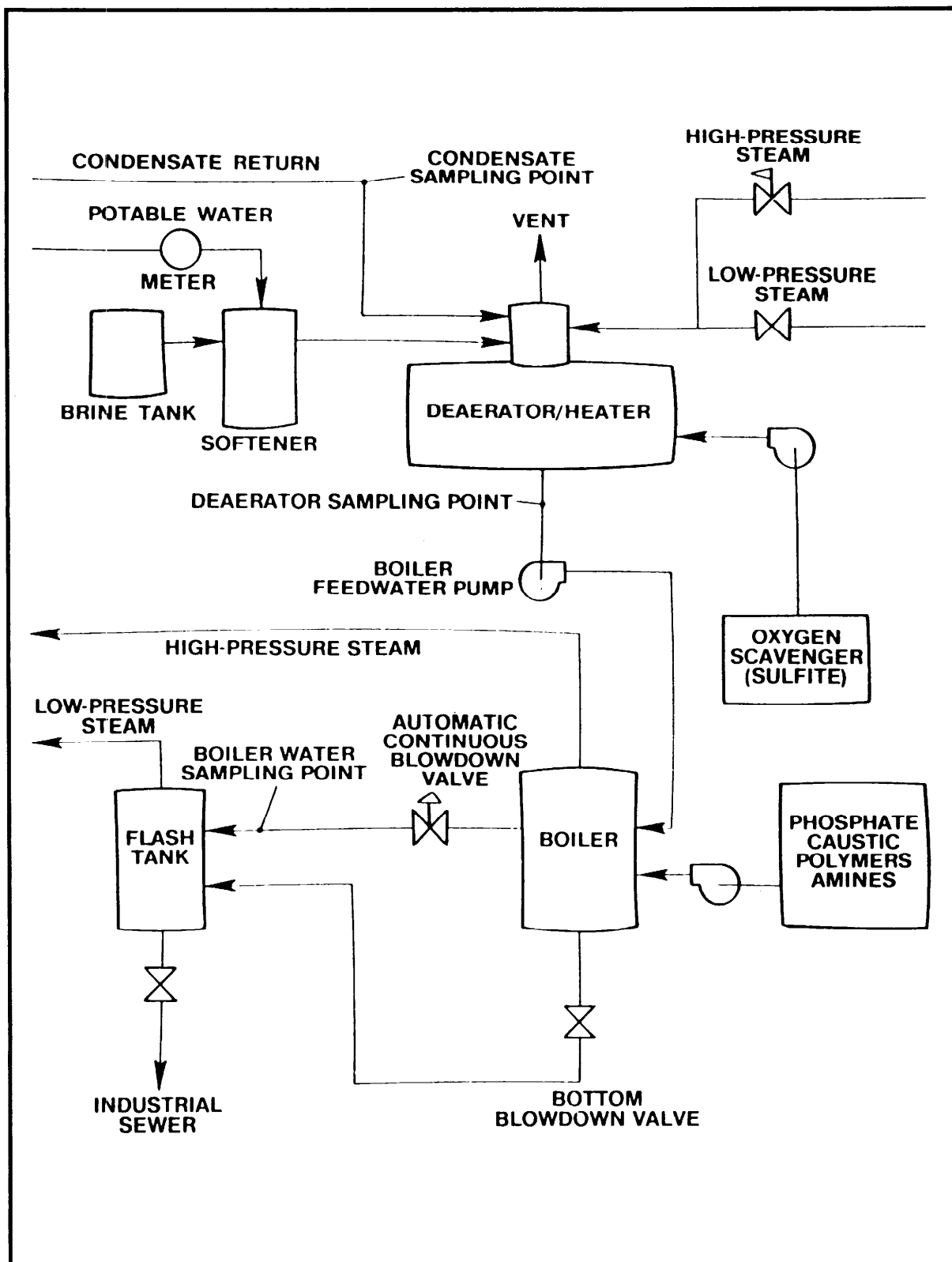
FIGURE C-8

Schematic of water treatment equipment at a small size unmanned boiler plant
with automatically controlled blowdown

Chemical	Purpose
caustic soda	alkalinity control for boilers with dealkalizers
sodium sulfite with cobalt catalyst	O_2 scavenging
sodium hexametaphosphate	hardness control
neutralizing amine	condensate corrosion control
polymeric conditioner	sludge dispersant

C. Implementation

Public Works personnel have responsibility for implementing steam boiler water treatment programs. Public Works will maintain supplies of caustic soda, sodium sulfite with metal catalyst, and sodium hexametaphosphate. Boiler plant operations personnel are responsible for obtaining these chemicals and maintaining a sufficient stock of chemicals at their respective boiler plants for one to two months of operation.

This section presents the specific procedures for treating the water in a steam boiler. Each Bill of Attendance is presented on a separate page for ease of copying them for the boiler rooms.

The following step-by-step procedures will be performed once per shift for each boiler at the plant.

Step No.	Description

1   On each boiler in operation, open the bottom blowdown valves according to the schedule in use at the plant. After some experience implementing this water treatment program, the schedule may be modified. However, any changes in bottom blowdown schedules should be explicitly approved by the boiler plant supervisor.

2   Turn on the cold water to the boiler water sample cooling coil. Open the specific boiler water line slowly until a steady stream of boiler water is flowing, free of sparging and flashing. Wait approximately two minutes. Slowly fill a clean sample container from the sample cooler, then close all valves. (Note: On low pressure boilers, samples of boiler water can frequently be obtained from site glass drains with only minimal flashing. Care should be taken in obtaining a sample in this manner due to the scalding nature of the boiler water and the potential of live steam purging through the site glass.)

3   Perform the following tests in order:

    * Conductivity (If conductivity exceeds limits, discard sample and repeat step #1 blowing down the mud drum until within limits.)

    * P Alkalinity (If P Alkalinity exceeds 600 ppm, discard sample and repeat step #1 blowing down the mud drum until within limits.)

    * Sulfite

      * Phosphate

4   Take samples of condensate from the various condensate return lines where the condensate is free of make-up water addition.

5   Analyze the samples of condensate for pH.

6   Record results on water treatment log for each boiler and condensate loop. Use the example forms provided as pages B-2 and B-3 or similar forms. Calculate the required chemical quantities.

* 7   Mix the powdered phosphate, powdered sulfite, liquid polymer, amine solution, and caustic flake with softened water in the proper chemical feed tank and fill with softened water. Adjust the pump stroke or speed to maintain the treatment limits.

8   Insure isolation valves of shot feeder are closed. Open the drain valve and then the top cap. When the shot feeder is half emptied, close the drain valve and add the necessary chemicals. Secure the top cap. Open the isolation valves on the shot feeder and close the by-pass valve. Wait at least five minutes while the feedwater pump is "ON" before proceeding to the next step. Refer to Figure C-8 for the exact location of these valves.

9   Open the bypass valve for the shot feeder and then close the isolation valves.

10   Adjust the automatic continuous blowdown controller setting to maintain the treatment limits. Once per week clean and calibrate the conductivity probes. (When the probe is found to be in excess of 200 micromhos in error, this calibration step may have to be accomplished more frequently.)

11   Record the quantities of chemicals added on a form similar to that provided as page B-4 of this document. The water treatment log should include comments or noted discrepancies. Particular attention should be given to changes to the settings of the automated continuous blowdown controller.

*   If the boilers are not equipped with individual chemical shot feeders, the sulfite, amines, phosphate, caustic, and polymers are added into the boiler feedwater line servicing all of the boilers. The chemical parameters of each boiler should be considered and the quantity of chemicals should be changed to maintain the minimum levels of phosphate and caustic in each of the boilers. Consideration should be given to the installation of a chemical feed pump for the neutralizing amines since it will be quite difficult to balance the pH of the returning condensate. The optimum location for injection of the amines is into the steam header departing the power plant.

9. SMALL SIZE STEAM PLANTS, UNMANNED WITH MANUAL CONTINUOUS BLOWDOWN CONTROLS.

A. Treatment Limits

Boiler water will be treated to maintain the following limits:

Parameter	Limits
Alkalinity, Total	700 ppm maximum as $CaCO_3$
Alkalinity, P	250-600 ppm as $CaCO_3$
Conductivity	2,500 umhos/cm (neutralized)
Hardness	< 0.3 ppm as $CaCO_3$
pH	10.5-11.2
Phosphate	40-70 ppm as PO_4
Polymeric Dispersant	As directed by manufacturer (e.g. 1 quart added per thousand pounds of steam generated)
Sulfite	40-70 ppm as SO_3

Manual continuous blowdown valves permit higher levels of dissolved solids in the boilers than with bottom blowdown alone. However, valve settings should be continually checked. Changes in makeup or condensate return rates significantly influence the dissolved solids level in boilers with a fixed setting on the continuous blowdown valve. A depiction of water treatment equipment for a small size boiler plant is provided as Figure C-9.

Produced steam should be chemically treated with neutralizing amines to maintain the pH of returning condensate between 7.5 and 8.5. A mixture of morpholine and cyclohexylamine is typically used for this purpose. Do not purchase these chemicals in concentrations greater than a 40 percent solution. Few power plant personnel have the necessary safety equipment to dilute these reagents from concentrated stocks. Also, avoid purchasing these chemicals in a solution strength less than 30 percent..

B. Chemicals Required

The following table details the chemicals required to implement this program. Note that filming amines are not listed in this table. Filming amine use should be restricted to injection over a period of several hours in large steam distribution systems immediately before seasonal shutdown. At plants with chronic condensate line corrosion control problems, satellite injection of filming amines may be needed. However, such a decision should be made only after a comprehensive evaluation of the plant water treatment system is accomplished.
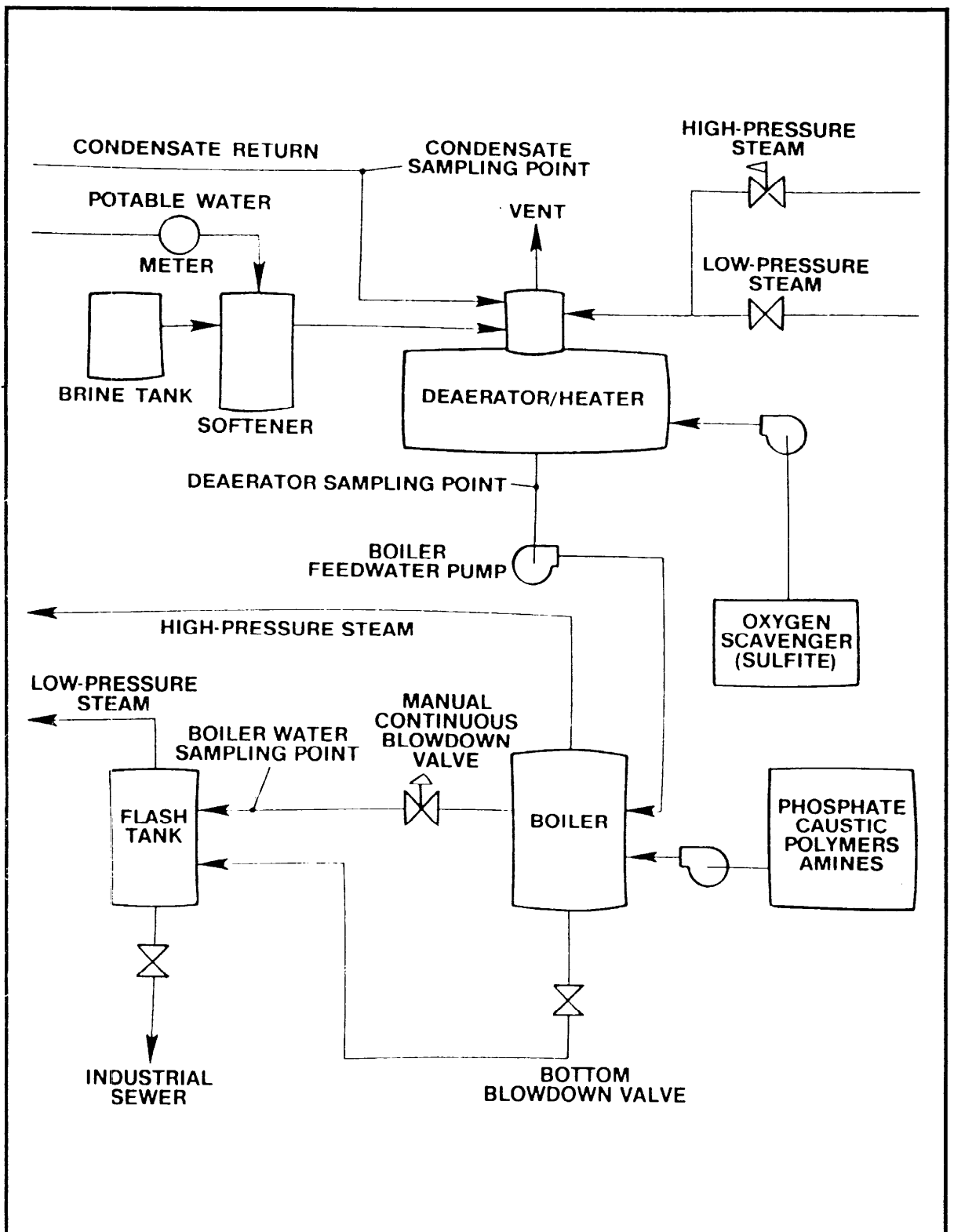
FIGURE C-9

Schematic of water treatment equipment at a small size unmanned boiler plant with manually controlled blowdown.

Chemical	Purpose
caustic soda	alkalinity control for boilers with dealkalizers
sodium sulfite with cobalt catalyst	O_2 scavenging
sodium hexametaphosphate	hardness control
neutralizing amine	condensate corrosion control
polymeric conditioner	sludge dispersant

C. Implementation

Public Works personnel have responsibility for implementing steam boiler water treatment programs. Public Works will maintain supplies of caustic soda, sodium sulfite with metal catalyst, and sodium hexametaphosphate. Boiler plant operations personnel are responsible for obtaining these chemicals and maintaining a sufficient stock of chemicals at their respective boiler plants for one to two months of operation.

This section presents the specific procedures for treating the water in a steam boiler. Each Bill of Attendance is presented on a separate page for ease of copying them for the boiler rooms.

The following step-by-step procedures will be performed once per shift for each boiler at the plant.

Step No.	Description

1   On each boiler in operation, open the bottom blowdown valves according to the schedule in use at the plant. After some experience implementing this water treatment program, the schedule may be modified. However, any changes in bottom blowdown schedules should be explicitly approved by the boiler plant supervisor.

2   Turn on the cold water to the boiler water sample cooling coil. Open the specific boiler water line slowly until a steady stream of boiler water is flowing, free of sparging and flashing. Wait approximately two minutes. Slowly fill a clean sample container from the sample cooler, then close all valves. (Note: On low pressure boilers, samples of boiler water can frequently be obtained from site glass drains with only minimal flashing. Care should be taken. in obtaining a sample in this manner due to the scalding nature of the boiler water and the potential of live steam purging through the site glass.)

3   Perform the following tests in order:

    * Conductivity (If conductivity exceeds limits, discard sample and repeat step #1 blowing down the mud drum until within limits.)

    * P Alkalinity (If P Alkalinity exceeds 600 ppm, discard sample and repeat step #1 blowing down the mud drum until within limits.)

* Sulfite

* Phosphate

4   Take samples of condensate from the various condensate return lines where the condensate is free of make-up water addition.

5   Analyze the samples of condensate for pH.

6   Record results on water treatment log for each boiler and condensate loop. Use the example forms provided as pages B-2 and B-3 or similar forms. Calculate the required chemical quantities.

* 7   Mix the powdered phosphate, powdered sulfite, liquid polymer, amine solution, and caustic flake with softened water in the proper chemical feed tank and fill with softened water. Adjust the pump stroke or speed to maintain the treatment limits.

8   Insure isolation valves of shot feeder are closed. Open the drain valve and then the top cap. When the shot feeder is half emptied, close the drain valve and add the necessary chemicals. Secure the top cap. Open the isolation valves on the shot feeder and close the by-pass valve. Wait at least five minutes while the feedwater pump is "ON" before proceeding to the next step. Refer to Figure C-9 for the exact location of these valves.

9   Open the bypass valve for the shot feeder and then close the isolation valves.

10   Adjust the manual continuous blowdown setting to maintain the treatment limits. (At some plants this valve adjustment step may have to be accomplished on a more frequent basis.)

11   Record the quantities of chemicals added on a form similar to that provided as page B-4 of this document. The water treatment log should include comments or noted discrepancies. Particular attention should be given to changes to the settings to the manual continuous blowdown control valve.

*   If the boilers are not equipped with individual chemical shot feeders, the sulfite, amines, phosphate, caustic, and polymers are added into the boiler feedwater line servicing all of the boilers. The chemical parameters of each boiler should be considered and the quantity of chemicals should be changed to maintain the minimum levels of phosphate and caustic in each of the boilers. Consideration should be given to the installation of a chemical feed pump for the neutralizing amines since it will be quite difficult to balance the pH of the returning condensate. The optimum location for injection of the amines is into the steam header departing the power plant.

10. SMALL SIZE STEAM PLANTS, UNMANNED WITH MANUAL BLOWDOWN CONTROLS.

A. Treatment Limits with Boilers Operating Below 300 psi

Boiler water will be treated to maintain the following limits:

Parameter	Limits
Alkalinity, Total	700 ppm maximum as $CaCO_3$
Alkalinity, P	250-600 ppm as $CaCO_3$
Conductivity	2,000 umhos/cm (neutralized)
Hardness	< 0.3 ppm as $CaCO_3$
pH	10.5-11.2
Phosphate	40-70 ppm as PO_4
Polymeric Dispersant	As directed by manufacturer (e.g. 1 quart added per thousand pounds of steam generated)
Sulfite	40-70 ppm as SO_3

The manual bottom blowdown valve periodically releases a flow of boiler water from the bottom portion of the boiler. This causes an increase in makeup water to the boiler to dilute the boiler water and prevent scale formation. If the conductivity of the water is not routinely checked, then it is possible that too much or insufficient quantities of blowdown will be released from the boiler. This can set up scaling conditions or waste valuable water by maintaining excessively low levels of dissolved solids in the boilers.

A depiction of water treatment equipment for a small size steam boiler plant is provided as Figure c-10.

Produced steam should be chemically treated with neutralizing amines to maintain the pH of returning condensate between 7.5 and 8.5. A mixture of morpholine and cyclohexylamine is typically used for this purpose. Do not purchase these chemicals in concentrations greater than a 40 percent solution. Few power plant personnel have the necessary safety equipment to dilute these reagents from concentrated stocks. Also, avoid purchasing these chemicals in a solution strength less than 30 percent.

B. Chemicals Required

The following table details the chemicals required to implement this program. Note that filming amines are not listed in this table. Filming amine use should be restricted to injection over a period of several hours in large steam distribution systems immediately before seasonal shutdown. At plants with chronic condensate line corrosion control problems, satellite injection of filming amines may be needed. However, such a decision should be made only after a comprehensive evaluation of the plant water treatment system is accomplished.
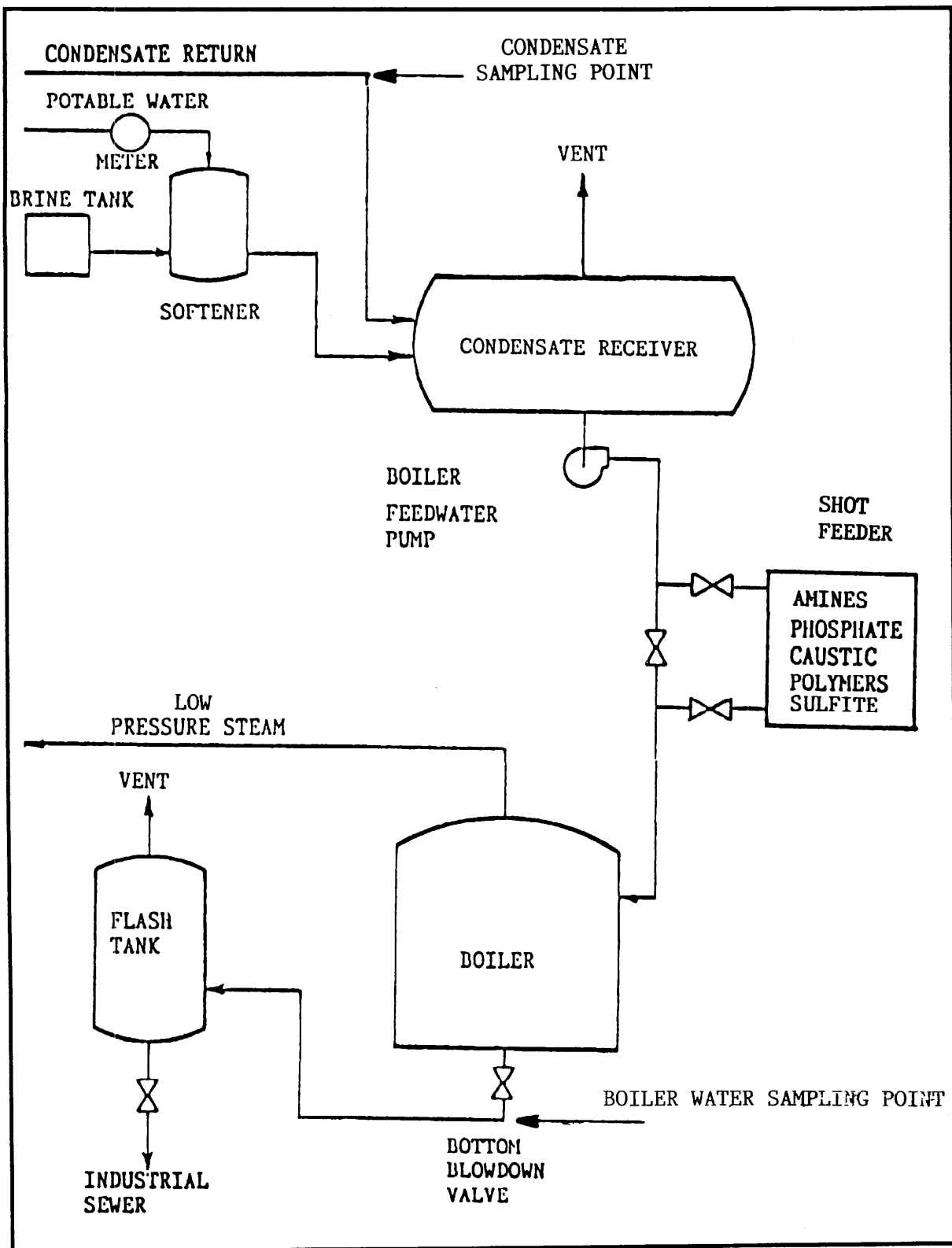
FIGURE C-10

Schematic of water treatment equipment at a small sized unmanned boiler plant with periodic bottom blowdown.

Chemical	Purpose
caustic soda	alkalinity control for boilers with dealkalizers
sodium sulfite with cobalt catalyst	O_2 scavenging
sodium hexametaphosphate	hardness control
neutralizing amine	condensate corrosion control
polymeric conditioner	sludge dispersant

C. Implementation

Public Works personnel have responsibility for implementing steam boiler water treatment programs. Public Works will maintain supplies of caustic soda, sodium sulfite with metal catalyst, and sodium hexametaphosphate. Boiler plant operations personnel are responsible for obtaining these chemicals and maintaining a sufficient stock of chemicals at their respective boiler plants for one to two months of operation.

This section presents the specific procedures for treating the water in a steam boiler. Each Bill of Attendance is presented on a separate page for ease of copying them for the boiler rooms.

The following step-by-step procedures will be performed once per shift for each boiler at the plant.

Step No.	Description

1   On each boiler in operation, open the bottom blowdown valves according to the schedule in use at the plant. After some experience implementing this water treatment program, the schedule may be modified. However, any changes in bottom blowdown schedules should be explicitly approved by the boiler plant supervisor.

2   Turn on the cold water to the boiler water sample cooling coil. Open the specific boiler water line slowly until a steady stream of boiler water is flowing, free of sparging and flashing. Wait approximately two minutes. Slowly fill a clean sample container from the sample cooler, then close all valves. (Note: On low pressure boilers, samples of boiler water can frequently be obtained from site glass drains with only minimal flashing. Care should be taken in obtaining a sample in this manner due to the scalding nature of the boiler water and the potential of live steam purging through the site glass.)

3   Perform the following tests in order:

    * Conductivity (If conductivity exceeds limits, discard sample and repeat step #1 blowing down the mud drum until within limits.)

    * P Alkalinity (If P Alkalinity exceeds 600 ppm, discard sample and repeat step #1 blowing down the mud drum until within limits.)

    * Sulfite

* Phosphate

4   Take samples of condensate from the various condensate return lines where the condensate is free of make-up water addition.

5   Analyze the samples of condensate for pH.

6   Record results on water treatment log for each boiler and condensate loop. Use the example forms provided as pages B-2 and B-3 or similar forms. Calculate the required chemical quantities.

* 7   Mix the powdered phosphate, powdered sulfite, liquid polymer, amine solution, and caustic flake with softened water in the proper chemical feed tank and fill with softened water. Adjust the pump stroke or speed to maintain the treatment limits.

8   Insure isolation valves of shot feeder are closed. Open the drain valve and then the top cap. When the shot feeder is half emptied, close the drain valve and add the necessary chemicals. Secure. the top cap. Open the isolation valves on the shot feeder and close the by-pass valve. Wait at least five minutes while the feedwater pump is "ON" before proceeding to the next step. Refer to Figure C-10 for the exact location of these valves.

9   Open the bypass valve for the shot feeder and then close the isolation valves.

10   Record the quantities of chemicals added on the water treatment log similar to that provided as page B-4 of this document. The water treatment log should include comments or noted discrepancies.

        * If the boilers are not equipped with individual chemical shot feeders, the sulfite, amines, phosphate, caustic, and polymers are added into the boiler feedwater line servicing all of the boilers. The chemical parameters of each boiler must be considered and the quantity of chemicals should be changed to maintain the minimum levels of phosphate and caustic in each of the boilers. Consideration should be given to the installation of a chemical feed pump for the neutralizing amines since it will be quite difficult to balance the pH of the returning condensate. The optimum location for injection of the amines is into the steam header departing the power plant.

11. HIGH TEMPERATURE HOT WATER (HTHW) BOILER PLANTS.

A. Treatment Limits for Pressurized Hot Water Systems Operating Between 350°F and 450°F

Treat high temperature hot water boiler/distribution systems to maintain the following limits:

Parameter	Limits
Hardness	0.3 ppm as $CaCO_3$
pH	8.5-9.5
Sulfite	20-40 ppm as SO_3

Periodic blowdown is also required at the boiler and/or at the ends of the piping network to control precipitated solids. The rate of blowdown depends upon the amount of dissolved or settled solids. For HTHW generators, the limits of total dissolved solids should be the same as for steam boilers operating between 350°F and 450°F.

Some boiler plants employ an expansion tank with pressurized live steam as a blanket atop the surface of the water in an expansion tank. While there is nothing wrong with this type of oxygen diffusion control a nitrogen blanket is far easier to maintain.

A depiction of the water treatment equipment for a typical high temperature hot water system is provided in Figure C-11.

B. Chemicals Required

The following table details the necessary chemicals which are required to implement this program.

Chemical	Purpose
sodium sulfite with cobalt catalyst	O_2 scavenging
polymeric conditioner	sludge dispersant
caustic soda	pH control

C. Implementation

Public Works personnel have responsibility for implementing water treatment programs for the high temperature hot water boilers. Public Works will maintain supplies of caustic soda, sodium sulfite with metal catalyst and polymeric dispersant. Boiler plant operations personnel are responsible for obtaining these chemicals and maintaining a sufficient stock of chemicals at their respective boiler plants for one to two months of operation.

This section presents the specific procedures for treating the water in the entire high temperature hot water loop and associated boilers. All of the water in the closed loop is common to the water in the recirculating boilers. This Bill of Attendance is presented on a separate page for ease of copying for the applicable boiler plants.
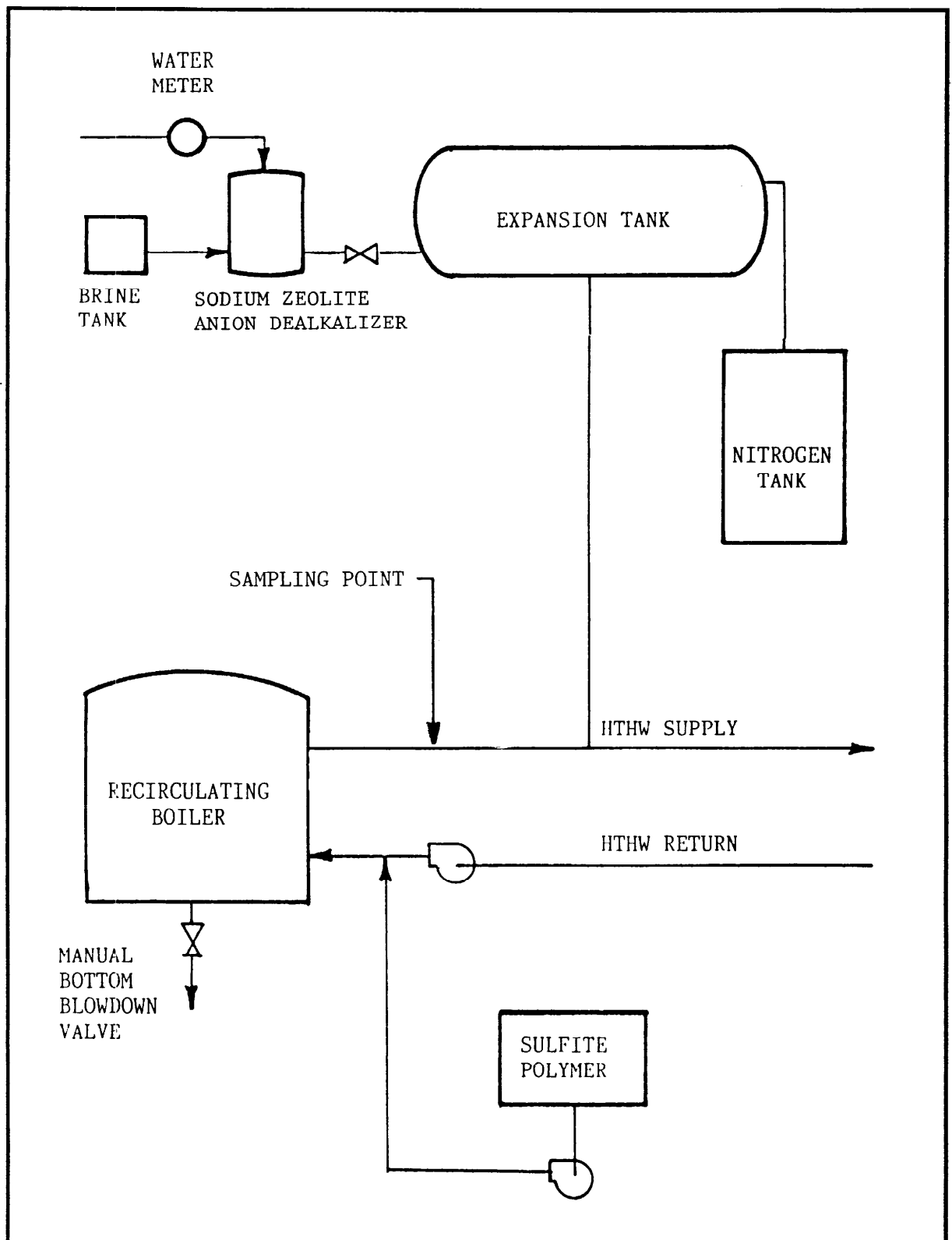
FIGURE C-11
Schematic of water treatment equipment at a high temperature
hot water heating system.

The following step-by-step procedures will be performed once per shift at the HTHW Plant.

Step no.	Description

1   Turn on the cold water to the high temperature hot water system sample cooling coil. Open the HTHW system feed line to the cooler slowly until a steady stream of system water is flowing, free of sparging and flashing. Wait approximately two minutes. Slowly fill a clean sample container from the sample cooler, then close all valves.

2   Perform the following tests in order:

* Sulfite

* pH

* Hardness

3   Record results on water treatment log. Use the example form provided as page B-3 or a similar form. Calculate the required chemical quantity of sodium sulfite. The pH and hardness are monitored to detect early indications of failure of the water softener on the make-up water line or any other system upsets. Caustic soda should be added to the HTHW system in gradually increasing amounts for pH control. Four hours of circulation through the system should be employed before retesting and pumping additional caustic into the system.

4   Mix the powdered sulfite and liquid polymer in the proper chemical feeder and fill with softened water. The dosage of the polymer should be in accordance with the manufacturer's recommendations (e.g. one quart per 5,000 gallons of make-up water.) Change the speed or stroke of the chemical feeder on large distribution systems. On smaller systems merely pump the chemical feed tank dry into the high temperature hot water loop.

5   Record the quantities of chemicals added on the water treatment log (e.g. page B-4 of this document or other similar form.) Include any comments or noted discrepancies.

12. LOW TEMPERATURE HOT WATER CLOSED LOOP BOILER SYSTEMS.

A. Treatment Limits for Boilers Operating Below 200°F

The closed loop system water will be treated to maintain the following limits:

Parameter	Limits
Nitrite Level	1,000 ppm as NO_2
pH	> 7.0

Most low temperature closed loop heating systems experience only minor makeup requirements from leakages at valves and pumps. The buffered nitrite water treatment program will provide an effective mechanism for control of corrosion for recirculating boilers as well as system piping, radiators, pumps and other ancillary items exposed to this water.

One of the few exceptions where this program should not be employed is at locales serviced with low pH makeup water (pH < 5). Where a low pH of the makeup water is a routine or occasional event, a molybdate treatment program should be employed.

Care should also be taken in preventing periodic maintenance to the heating system from significantly depleting the nitrite levels dissolved in the hot water. When the nitrite concentration falls to very low levels, the corrosion inhibitors will actually stimulate corrosion to the boiler and distribution piping.

A depiction of a typical water treatment system for a closed loop heating system is provided in Figure C-12.

B. Chemicals Required

The following table details the necessary chemical formulation available through Federal Stock Number.

Chemical	Purpose
buffered sodium nitrite with copper corrosion inhibitors	corrosion control

C. Implementation

Public Works personnel have the responsibility for implementing the water treatment program for the closed loop systems. Public Works will maintain supplies of the buffered nitrite inhibitor chemicals. Roving maintenance personnel of the Heating Shop are responsible for securing these chemicals from the warehouse area. Maintaining a stock of chemicals at the various mechanical rooms is neither necessary nor recommended for the closed loop treatment program.

This section presents the specific procedures for treating the water in a closed loop heating system. Each Bill of Attendance is presented on a separate page for ease of copying these procedures for the mechanical rooms.
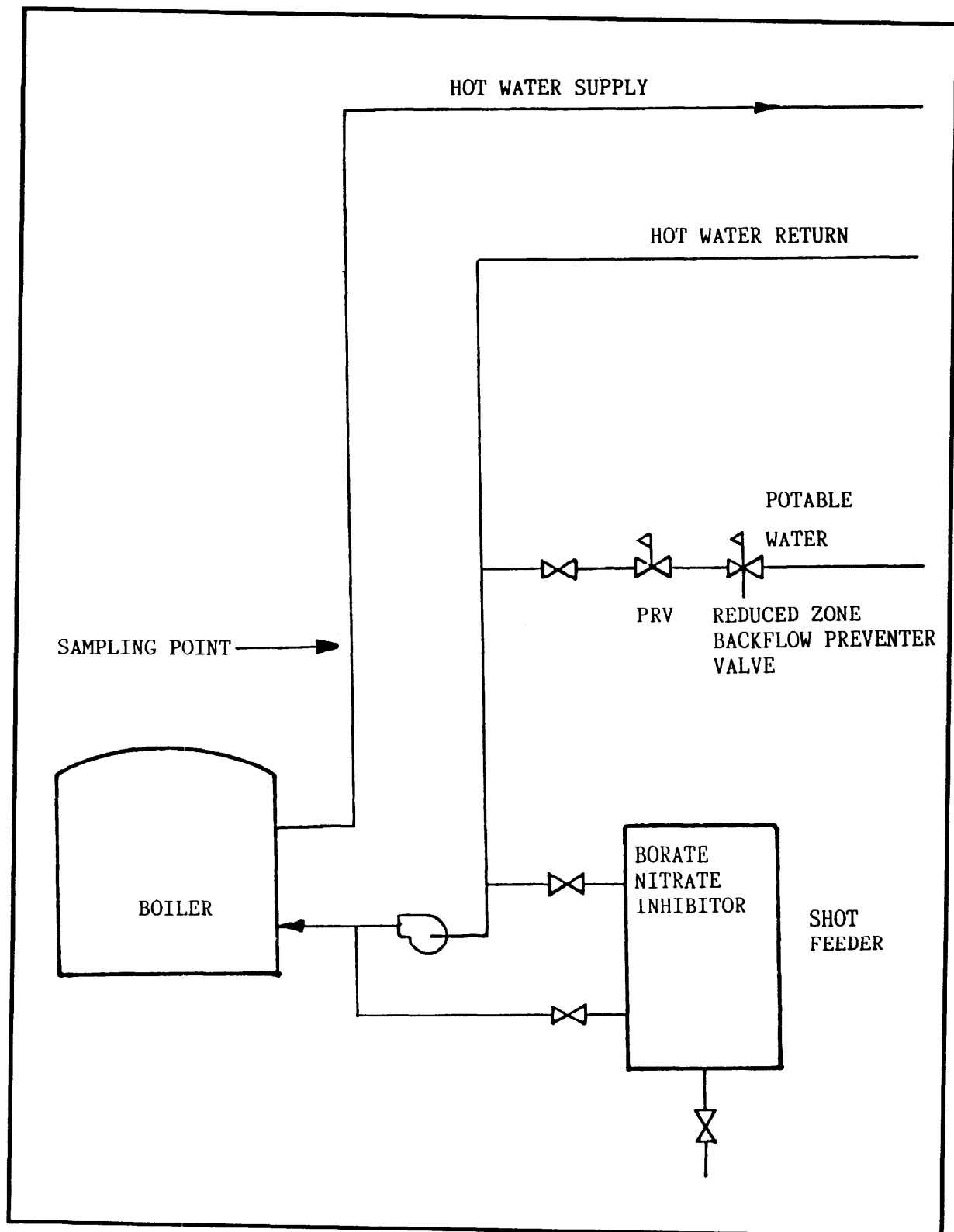
FIGURE C-12
Typical water treatment equipment configuration for a low temperature
closed loop heating system.

The following step-by-step procedures will be performed once per week for six weeks and then once every three months thereafter, or whenever the system is partially or completely drained for maintenance or modification:

Step no.	Description

1   Obtain a sample of the closed loop water in the distribution system from any valve on the boiler or distribution system. Insure that the make-up valve is closed before taking the sample and re-opened immediately afterwards. Allow the water to flow until the line is free of sediment and rust.

2   Perform the following tests:

       * Nitrite

       * pH

3   Record the results in the water treatment log for the unit on a form similar to that provided as page B-5 of this document. If the pH is outside the limits, the solution is heavily rust colored, or the water has a definite musty smell, the entire system should be drained, refilled with potable water, and Step 2 repeated.

4   Calculate the required amount of chemicals to be added to the system based on the nitrite levels from Step 2 and the estimated volume of water in the boiler(s) and the closed loop distribution system. (If no estimate is available on the volume of water in the heating system, then add a specific amount of inhibitor and check the effect on the concentration of nitrites in the system after several hours of circulation. For example, after adding five pounds of the inhibitor, the nitrite concentration is found to be 250 ppm. If the system had previously been filled only with water, then the remaining amount of inhibitor needed to treat the system can be calculated as follows.)

$$\frac{(1{,}000 \text{ ppm})}{(250 \text{ ppm})} (\text{five pounds}) - (\text{five pounds}) =$$

$$(4) \ X \quad (\text{five pounds}) - (\text{five pounds}) =$$

$$20 \text{ pounds} - 5 \text{ pounds} = 15 \text{ pounds}$$

5   Insure isolation valves of shot feeder are closed. Open the drain valve and then the top cap. When the shot feeder is half emptied, close the drain valve and add the necessary chemicals. Secure the top cap. Open the isolation valves on the shot feeder and close the by-pass valve. Wait at least five minutes while the circulating pump is "ON" before proceeding to the next step. Refer to Figure C-12 for the exact location of these valves.

6   Open the bypass valve for the shot feeder and then close the isolation valves.

7   Record the quantities of chemicals added in the water treatment log. Include any comments or discrepancies.

13. UNFIRED PRESSURE VESSEL (UFPV) LOW PRESSURE STEAM SYSTEMS.

A. Treatment Limits for UFPV's Operating Below 300 psi

The UFPV water will be treated to maintain the following limits:

Parameter	Limits
Alkalinity, Total	700 ppm maximum as $CaCO_3$
Alkalinity, P	250-600 ppm as $CaCO_3$
Conductivity	2,000 umhos/cm (neutralized)
Hardness	< 0.3 ppm as $CaCO_3$
pH	10.5-11.2
Phosphate	40-70 ppm as PO_4
Polymeric Dispersant	As directed by manufacturer (e.g. 1 quart added per thousand pounds of steam generated)
Sulfite	40-70 ppm as SO_3

The manual bottom blowdown valve periodically releases a flow of boiler water from the bottom portion of the UFPV. This causes an increase in makeup water to the boiler to dilute the boiler water and prevent scale formation. If the conductivity of the water is not routinely checked, then it is possible that too much or insufficient quantities of blowdown will be released from the boiler. This can set up scaling conditions or waste valuable water by maintaining excessively low levels of dissolved solids in the boilers.

A depiction of water treatment equipment for a small size steam UFPV is provided as Figure C-13.

Produced steam should be chemically treated with neutralizing amines to maintain the pH of returning condensate between 7.5 and 8.5. A mixture of morpholine and cyclohexylamme is typically used for this purpose. Do not purchase these chemicals in concentrations greater than a 40 percent solution. Few power plant personnel have the necessary safety equipment to dilute these reagents from concentrated stocks. Also, avoid purchasing these chemicals in a solution strength less than 30 percent.

B. Chemicals Required

The following table details the chemicals required to implement this program. Note that filming amines are not listed on this table. Filming amines should be restricted to injection over a period of several hours in large steam distribution systems immediately before seasonal shutdown. At plants with chronic condensate line corrosion control problems, satellite injection of filming amines may be needed. However, such a decision should be made only after a comprehensive evaluation of the plant water treatment system is accomplished.
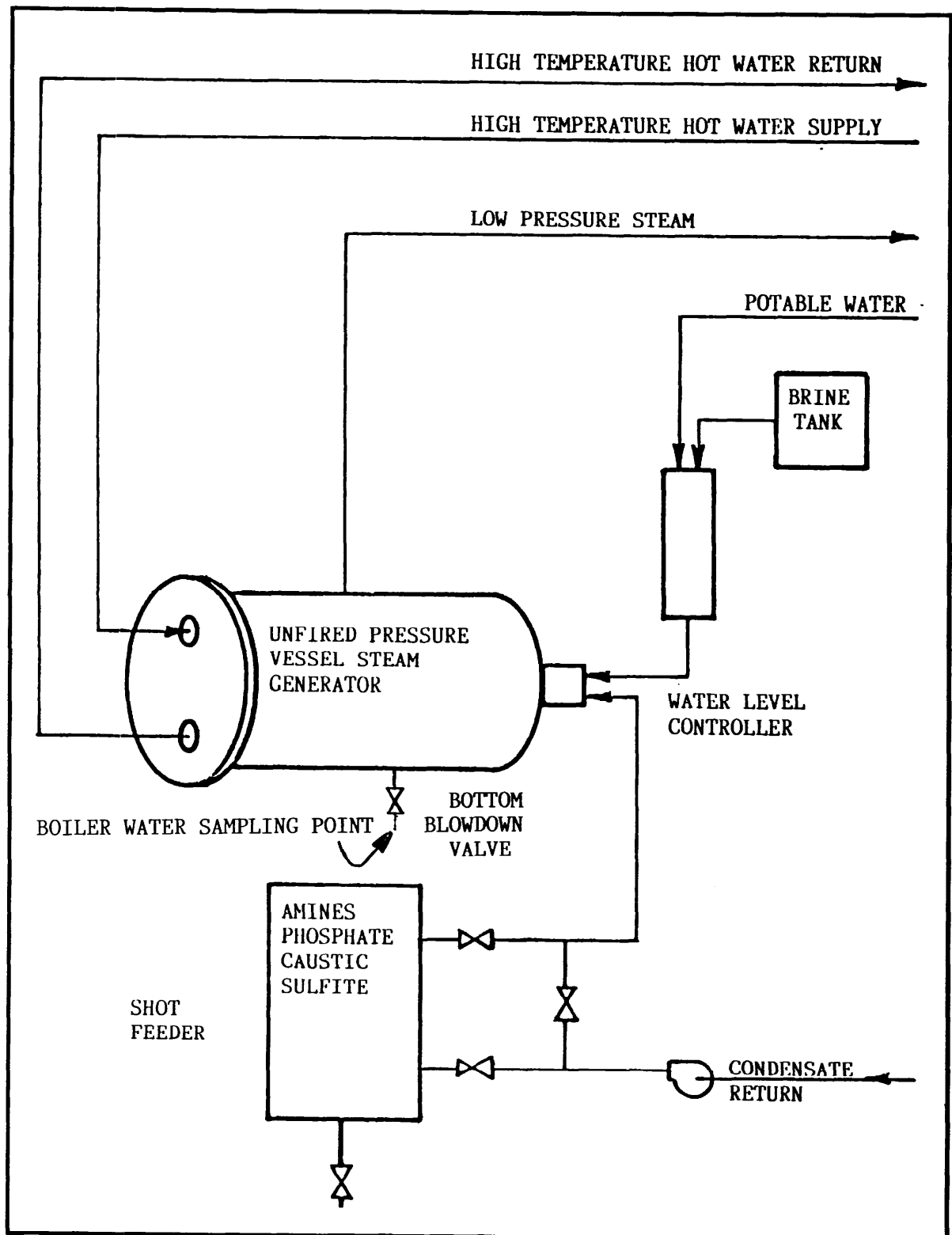
C-51

FIGURE C-13
Schematic of water treatment equipment at a small size
Unfired Pressure Vessel (UFPV) installation

Chemical	Purpose
caustic soda	alkalinity control for boilers with dealkalizers
sodium sulfite with cobalt catalyst	O_2 scavenging
sodium hexametaphosphate	hardness control
neutralizing amine	condensate corrosion control
polymeric conditioner	sludge dispersant

C. Implementation

Public Works personnel have the responsibility for implementing steam boiler water treatment programs. Public Works will maintain supplies of caustic soda, sodium sulfite with metal catalyst, and sodium hexametaphosphate. Individual UFPV plant operations personnel are responsible for obtaining these chemicals and maintaining a stock of chemicals at their respective boiler plants necessary for one to two months of operation.

This section presents the specific procedures for treating the water in a steam boiler. Each Bill of Attendance is presented on a separate page for ease of copying them for the boiler rooms.

The following step-by-step procedures will be performed once per week for each UFPV.

step no.   **Description**

1   On each UFPV in operation, open the bottom blowdown valves according to the schedule currently in use at the plant. After some experience implementing this water treatment program, the schedule may be modified. However, any changes in bottom blowdown schedules should be explicitly approved by the boiler plant supervisor.

2   Turn on the cold water to the boiler water sample cooling coil for the UFPV. Open the boiler water line slowly until a steady stream of boiler water is flowing, free of sparging and flashing. Wait approximately two minutes. Slowly fill a clean sample container from the sample cooler, then close all valves. (Note: On low pressure UFPV's, samples of boiler water can frequently be obtained from site glass drains with only minimal flashing. Care should be taken in obtaining a sample in this manner due to the scalding nature of the boiler water and the potential of live steam purging through the site glass.)

3   Perform the following tests in order:

    * Conductivity (If conductivity exceeds limits, discard sample and repeat step #1 blowing down the mud drum until within limits.)

    * P Alkalinity (If P Alkalinity exceeds 600 ppm, discard sample and repeat step #1 blowing down the mud drum until within limits.)

    * Sulfite

    * Phosphate

4   Take samples of condensate from the various condensate return lines where the condensate is free of make-up water addition.

5   Analyze the samples of condensate for pH.

6   Record results on water treatment log for each boiler and condensate loop. Use the example forms provided as pages B-2 and B-3 or similar forms. Calculate the required chemical quantities.

* 7   Mix the powdered sulfite, powdered phosphate, liquid polymer, amine solution, and caustic flake with softened water in the proper chemical feed shot feeder and fill with softened water.

8   Insure isolation valves of shot feeder are closed. Open the drain valve and then the top cap. When the shot feeder is half emptied, close the drain valve and add the necessary chemicals. Secure the top cap. Open the isolation valves on the shot feeder and close the by-pass valve. Wait at least five minutes while the feedwater pump is "ON" before proceeding to the next step. Refer to Figure D-13 for the exact location of these valves.

9   Open the bypass valve for the shot feeder and then close the isolation valves.

10   Record the quantities of chemicals added on the water treatment log (e.g. a form similar to that provided as page B-4.) Include any comments or noted discrepancies.

14. CLOSED LOOP CHILLED WATER SYSTEMS.

A. Treatment Limits for Systems Operating Between 40°F and 110°F

The closed loop system water will be treated to maintain the following limits:

Parameter	Limits
Nitrite Level	1,000 ppm as NO_2
pH	> 7.0

Most closed loop chilled water systems experience only minor makeup requirements from leakages at valves and pumps. The buffered nitrite water treatment program will provide an effective mechanism for control of corrosion for chillers as well as system piping, heat exchangers, pumps and other ancillary items exposed to this water.

One of the few exceptions where this program should not be employed is at locales serviced with low pH makeup water (pH < 5). Where a low pH of the makeup water is a routine or occasional event, a molybdate treatment program should be employed.

Care should also be taken in preventing periodic maintenance to the heating system from significantly depleting the nitrite levels dissolved in the hot water. When the nitrite concentration falls to very low levels, the corrosion inhibitors will actually stimulate corrosion to the boiler and distribution piping.

A depiction of a typical water treatment system for a closed loop heating system is provided in Figure C-14.

B. Chemicals Required

The following table details the necessary chemical formulation available through Federal Stock Number.

Chemical	Purpose
buffered sodium nitrite with copper corrosion inhibitors	corrosion control

C. Implementation

Public Works personnel have the responsibility for implementing the water treatment program for the closed loop systems. Public Works will maintain supplies of the buffered nitrite inhibitor chemicals. Roving maintenance personnel of the refrigeration shop are responsible for securing these chemicals from the warehouse area. Maintaining a stock of chemicals at the various mechanical rooms is neither necessary nor recommended for the closed loop treatment program.

This section presents the specific procedures for treating the water in a closed loop heating system. Each Bill of Attendance is presented on a separate page for ease of copying them for the mechanical rooms.
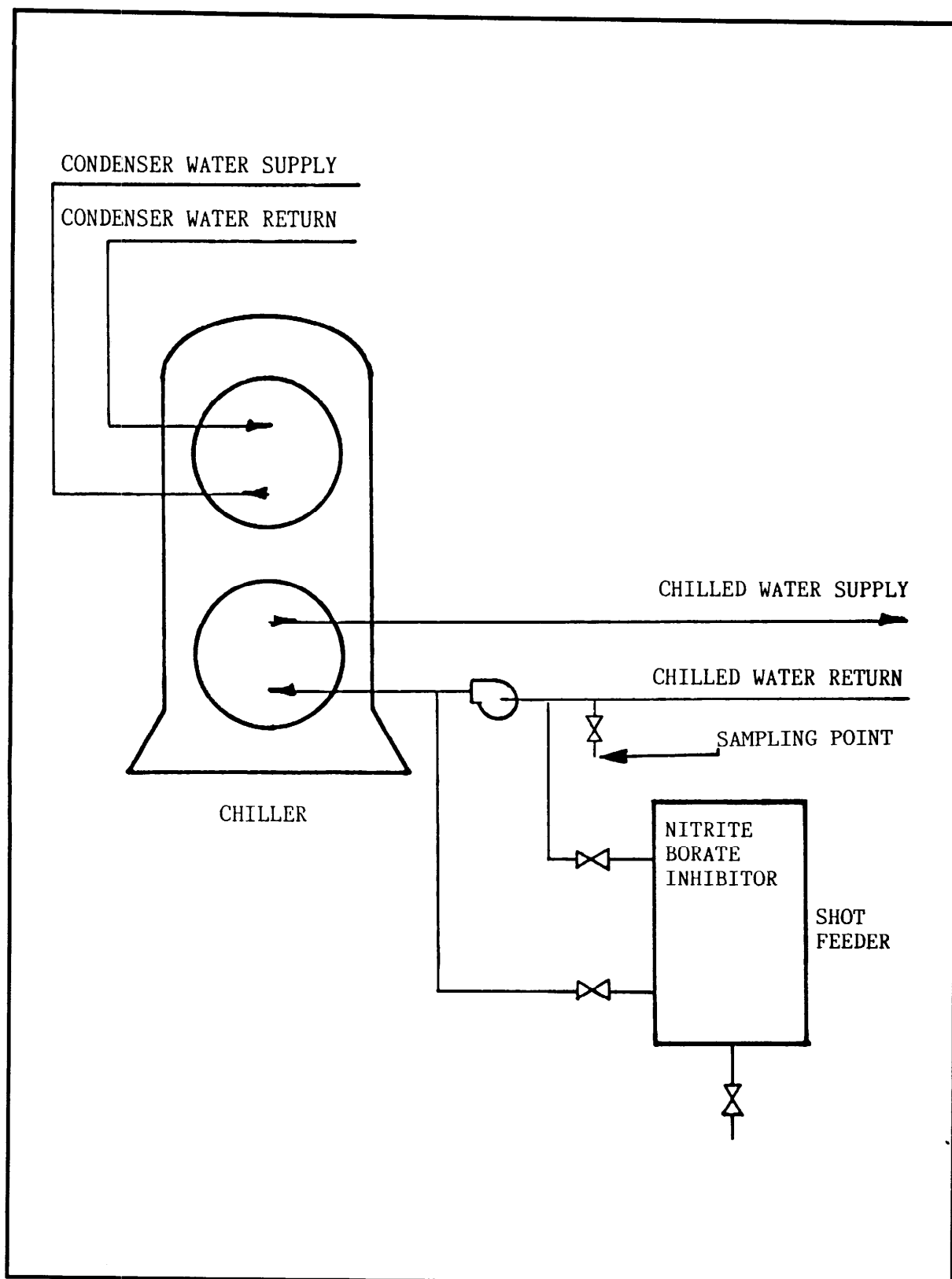
FIGURE C-14
Typical water treatment equipment configuration
for a closed loop chilled water system.

The following step-by-step procedures will be performed once per week for six weeks and then once every three mouths thereafter, or whenever the system is partially or completely drained for maintenance or modification:

Step no   **Description**

1   Obtain a sample of the closed loop chilled water in the distribution system from any valve on the chiller or distribution system. Insure that the make-up valve is closed before taking the sample and re-opened immediately afterwards. Allow the water to flow until the line is free of sediment and rust.

2   Perform the following tests:

        * Nitrite

        * pH

3   Record the results in the water treatment log for the unit. Use a form similar to that provided as page B-5 of this document. If the pH is outside the limits, the solution is heavily rust colored, or the water has a definite musty smell, the entire system should be drained, refilled with potable water, and Step 2 repeated.

4   Calculate the required amount of chemicals to be added to the system based on the nitrite levels from Step 2 and the estimated volume of water in the boiler(s) and the closed loop distribution system. (If no estimate is available on the volume of water in the heating system, then add a specific amount of inhibitor and check the effect on the concentration of nitrite in the system after several hours of circulation. For example, after adding five pounds of the inhibitor, the nitrite concentration is found to be 250 ppm. If the system had previously been filled only with water, then the remaining amount of inhibitor needed to treat the system can be calculated as follows.)

$$\frac{(1{,}000 \text{ ppm}) \text{ (five pounds)} - \text{(five pounds)} =}{(250 \text{ ppm})}$$

$$(4) \text{ X } \text{ (five pounds)} - \text{(five pounds)} =$$

$$20 \text{ pounds} - 5 \text{ pounds} = 15 \text{ pounds}$$

5   Insure isolation valves of shot feeder are closed. Open the drain valve and then the top cap. When the; shot feeder is half emptied, close the drain valve and add the necessary chemicals. Secure the top cap. Open the isolation valves on the shot feeder and close the by-pass valve. Wait at least five minutes while the circulating pump is "ON" before proceeding to the next step. Refer to Figure C-14 for the exact location of these valves.

6   Open the bypass valve for the shot feeder and then close the isolation valves.

7   Record the quantities of chemicals added in the water treatment log. Include any comments or discrepancies.

15. LARGE COOLINGTOWER SYSTEMS WITH AUTOMATIC ACID FEED AND AUTOMATIC BLOWDOWN CONTROLLERS.

A. Treatment Limits for Cooling Towers > 100 Ton Capacity

The open loop system water (condenser water) will be treated to maintain the following limits:

Parameter	Limits
Phosphate Level	20 - 30 ppm as PO_4
pH	7.2 - 7.8
Conductivity	2,000 - 2,200 umhos*
Biocide	As assigned by manufacturer

*This value may be adjusted to account for future changes in the chemistry of the makeup water. However, do not permit the cycles of concentration to exceed seven.

The pH of the condenser water is a very critical parameter for the control of both corrosion and scale in an open loop water system. Acid feed is not needed on small cooling towers (< 50 tons cooling capacity) or on larger towers serviced by makeup water with relatively low alkalinity and hardness. When the alkalinity is below 80 mg/L as $CaCO_3$ and the hardness is less than 60 mg/L as $CaCO_3$, the continued concentration of the water in the tower through evaporation will not significantly reduce the pH as long as the cycles of concentration are kept below five to seven.

The cycles of concentration can be readily checked on a yearly basis by measuring the chloride levels ii both the condenser water and the makeup water.

$$COC = \frac{\text{Chloride Concentration in Condenser Water}}{\text{Chloride Concentration in Makeup Water}}$$

B. Chemicals Required

The following table details the necessary chemicals available through GSA approved listings:

Chemical	Purpose
sulfuric acid	pH control
phosphate/polymer	corrosion/scale inhibitor
biocides	biological and foulant control

C. Implementation

Figure C-15 shows a typical arrangement for two chemical feed pumps, the cooling tower controller and the corrosion coupons for steel and copper. Deviations from this general configuration may be required due to unusual installations (e.g. a cooling tower mounted on the roof several stories above the chemical feed equipment in a basement mechanical room). However, the blow-
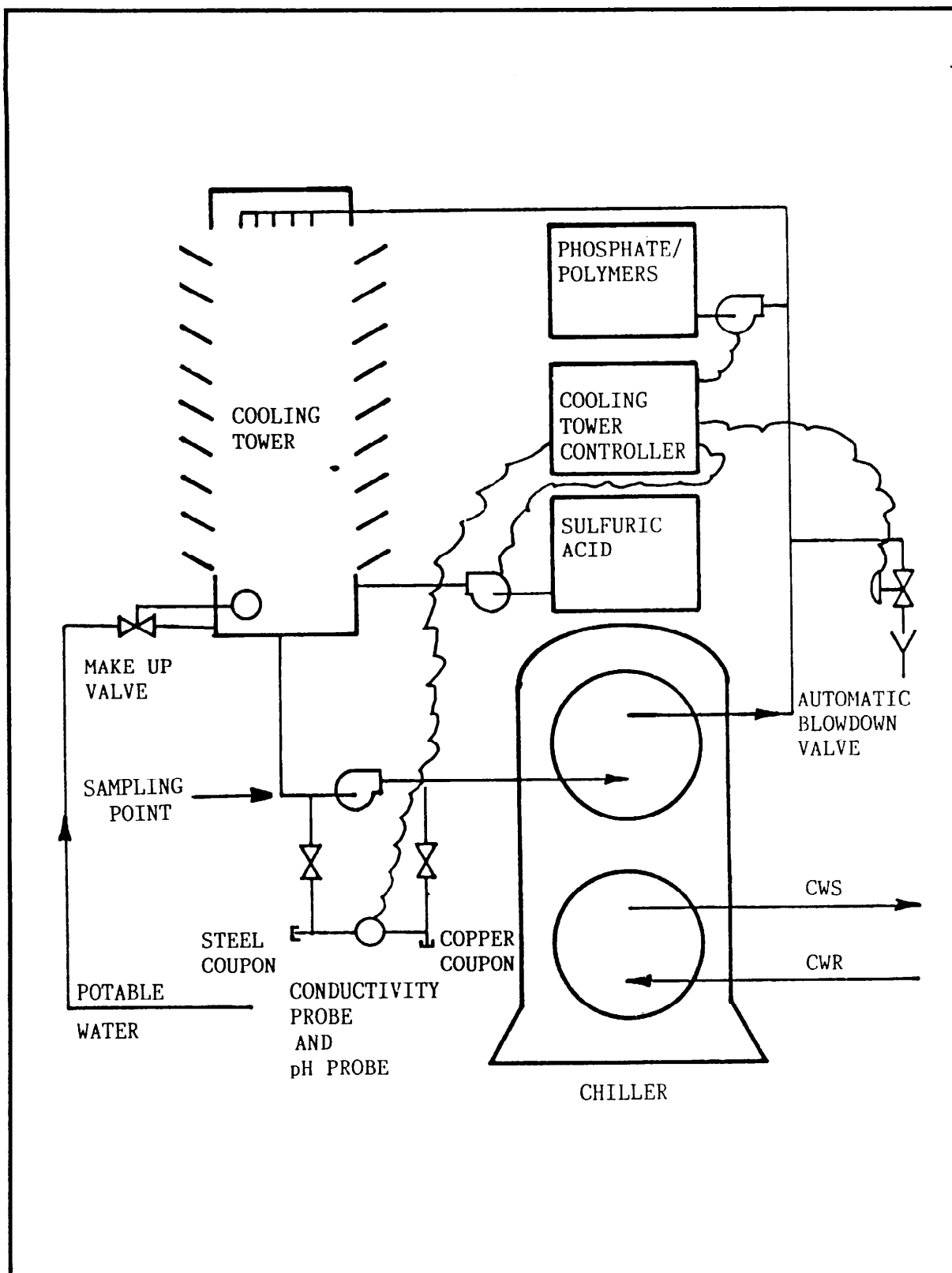
FIGURE C-15
Typical water treatment equipment configuration for a large cooling tower
with an automated tower controller and acid feed.

down valve and chemical feed pumps should never be configured to permit the injection of chemicals directly into a flow of water discharging out the blowdown valve. Also, distance of piping should be considered in the operation of the pH controlled sulfuric acid addition to the system to preclude a drop in pH well below the minimum of 7.2 units.

Some cooling towers will also necessitate the installation of a side stream filter to continuously remove suspended solids. Dirt continuously circulating through a condenser water system will erode valve seats and pump seals.

This section presents the specific procedures for treating the water in an open loop condenser water system. Each Bill of Attendance is presented on a separate page for ease of copying these procedures for the mechanical rooms.

The following step-by-step procedures will be performed once per week after the cooling season begins and cease at its completion for cooling towers idle during the heating season:

Step no.	Description
1	Obtain a sample of the open loop condenser water in the distribution system from any valve on the tower, chiller or distribution system. Insure that the makeup valve is closed before taking the sample and re-opened immediately afterwards. Allow the water to flow until the line is free of sediment and rust.
2	Perform the following tests:

        * Phosphate

        * pH

        * Conductivity

        * Biocide

3	Record the results in the water treatment log for the unit. Use a form similar to that provided as page B-4 of this document. If the pH is well outside the limits, the solution is heavily rust colored, or the water has a heavy musty smell, the entire system should be drained, refilled with potable water, and Step 2 repeated.
4	Adjust the operating time, pump speed and/or stroke to maintain the proper levels of phosphate/polymer mix, and the biocide as determined from the residual levels from Step 2 and the physical conditions noted for the growth of algae. If no biological growth are in evidence, then the biocide can be cautiously decreased in dosage.
5	If a shot feeder is employed for biocide injection, insure the isolation valves of shot feeder are closed. Open the drain valve and then the top cap. When the shot feeder is half emptied, close the drain valve and add the necessary chemicals. Secure the top cap. Open the isolation valves on the shot feeder and close the by-pass valve. Wait at least five minutes while the circulating pump is "ON" before proceeding to the next step.
6	Open the bypass valve for the shot feeder and then close the isolation valves.

7   Adjust the pH control settings on the Tower Controller to maintain the proper pH in the system.

8   Record the quantities of chemicals added in the water treatment log. This typically will be confined to the replacement of a given chemical drum with a full container. Include any comments or discrepancies.

9   Clean and calibrate the pH and conductivity probes and remove all empty chemical storage drums from the mechanical room.

16. COOLING TOWER SYSTEMS WITH AUTOMATIC BLOWDOWN CONTROLLERS.

A. Treatment Limits for Cooling Towers > 50 Ton Capacity

The open loop system water (condenser water) will be treated to maintain the following limits:

Parameter	Limits
Phosphate Level	20-30 ppm as PO_4
pH	7.5 - 8.5
Conductivity	2,000 - 2,200 umhos*
Biocide	As assigned by manufacturer

*This value may be adjusted to account for future changes in the chemistry of the makeup water. However, do not permit the cycles of concentration to exceed seven.

The pH of the condenser water is a very critical parameter for the control of both corrosion and scale in an open loop water system. Acid feed is not needed on small cooling towers (< 50 tons cooling capacity) or on larger towers serviced by makeup water with relatively low alkalinity and hardness. When the alkalinity is below 80 mg/L as $CaCO_3$ and the hardness is less than 60 mg/L as $CaCO_3$, the continued concentration of the water in the tower through evaporation will not significantly reduce the pH as long as the cycles of concentration are kept below five to seven.

The cycles of concentration can be readily checked on a yearly basis by measuring the chloride levels in both the condenser water and the makeup water.

$$COC = \frac{\text{Chloride Concentration in Condenser Water}}{\text{Chloride Concentration in Makeup Water}}$$

B. Chemicals Required

The following table details the necessary chemicals available through GSA approved listings:

Chemical	Purpose
phosphate/polymer	corrosion/scale inhibitor
biocides	biological and foulant control

C. Implementation

Figure C-16 shows a typical arrangement for a chemical feed pump, the cooling tower controller and the corrosion coupons for steel and copper. Deviations from this general configuration may be required due to unusual installations (e.g. a cooling tower mounted on the roof several stories above the chemical feed equipment in a basement mechanical room). However, the blowdown valve and chemical feed pump should never be configured to permit the injection of chemicals directly into a flow of water discharging out the blowdown valve.

Some cooling towers will also necessitate the installation of a side stream filter to continuously remove suspended solids. Dirt continuously circulating through a condenser water system will
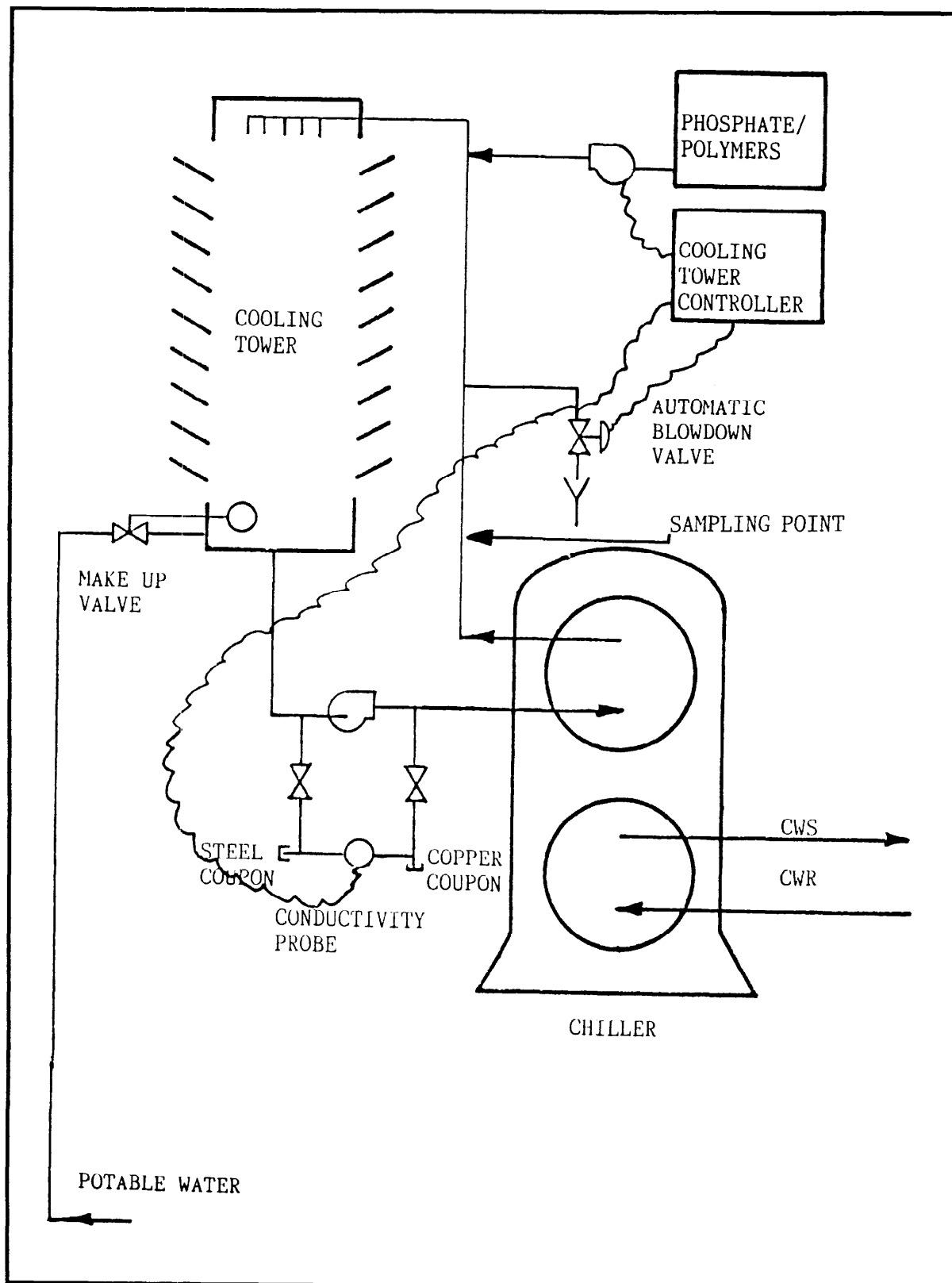
FIGURE C-16
Typical water treatment equipment configuration for a cooling tower
with an automatic controller.

erode valve seats and pump seals.

This section presents the specific procedures for treating the water in an open loop condenser water system. Each Bill of Attendance is presented on a separate page for ease of copying these procedures for the mechanical rooms.

The following stepby-step procedures will be performed once per week after the cooling season begins and cease at its completion for cooling towers idle during the heating season:

step no.   **Description**

1   Obtain a sample of the open loop condenser water in the distribution system from any valve on the tower, chiller or distribution system. Insure that the make-up valve is closed before taking the sample and re-opened immediately afterwards. Allow the water to flow until the line is free of sediment and rust.

2   Perform the following tests:

* Phosphate

* pH

* Conductivity

* Biocide

3   Record the results in the water treatment log for the unit. Use a form similar to that provided as page B-4 of this document. If the pH is well outside the limits, the solution is heavily rust colored, or the water has a heavy musty smell, the entire system should be drained, refilled with potable water, and Step 2 repeated.

4   Adjust the operating time, pump speed and/or stroke to maintain the proper levels of phosphate/polymer mix, and the biocide as determined from the residual biocide levels from Step 2 and the physical conditions noted for the growth of algal and other bacterial foulants. If no biological growth are in evidence, then the biocide can be cautiously decreased in dosage.

5   If a shot feeder is employed for biocide injection, insure the isolation valves of shot feeder are closed. Open the drain valve and then the top cap. When the shot feeder is half emptied, close the drain valve and add the necessary chemicals. Secure the top cap. Open the isolation valves on the shot feeder and close the by-pass valve. Wait at least five minutes while the circulating pump is "ON" before proceeding to the next step.

6   Open the bypass valve for the shot feeder and then close the isolation valves.

7   Record the quantities of chemicals added in the water treatment log. This typically will be confined to the replacement of a given chemical drum with a full container. Include any comments or discrepancies.

8   Clean and calibrate the tower controller conductivity probe and remove all empty chemical storage drums.

17. COOLING TOWERS WITH MANUAL CONTROLS.

A. Treatment Limits for Cooling Towers > 10 Tons Capacity

The open loop system water (condenser water) will be treated to maintain the following limits:

Parameter	Limits
Phosphate Level	30-40 ppm as PO_4
pH	7.5 - 8.5
Conductivity	2,000 umhos*
Biocide	As assigned by manufacturer

*This value may be adjusted to account for future changes in the chemistry of the makeup water. However, do not permit the cycles of concentration to exceed seven.

The pH of the condenser water is a very critical parameter for the control of both corrosion and scale in an open loop water system. Acid feed is not needed on small cooling towers (< 50 tons cooling capacity) or on larger towers serviced by makeup water with relatively low alkalinity and hardness. When the alkalinity is below 80 mg/L as $CaCO_3$ and the hardness is less than 60 mg/L as $CaCO_3$, the continued concentration of the water in the tower through evaporation will not significantly reduce the pH as long as the cycles of concentration are kept below five to seven.

The cycles of concentration can be readily checked on a yearly basis by measuring the chloride levels in both the condenser water and the makeup water.

$$COC = \frac{\text{Chloride Concentration in Condenser Water}}{\text{Chloride Concentration in Makeup Water}}$$

B. Chemicals Required

The following table details the necessary chemicals available through GSA approved listings:

Chemical	Purpose
phosphate/polymer	corrosion/scale inhibitor
biocides	biological and foulant control

C. Implementation

Figure C-17 shows a typical arrangement for a chemical shot feeder, and the corrosion coupons for steel and copper. Deviations from this general configuration may be required due to unusual installations (e.g. a cooling tower mounted on the roof several stories above the chemical feed equipment in a basement mechanical room). However, the manual blowdown valve and chemical shot feeder should never be configured to permit the injection of chemicals directly into a flow of water discharging out the blowdown valve.

Some cooling towers will also necessitate the installation of a side stream filter to continuously remove suspended solids. Dirt continuously circulating through a condenser water system will erode valve seats and pump seals.
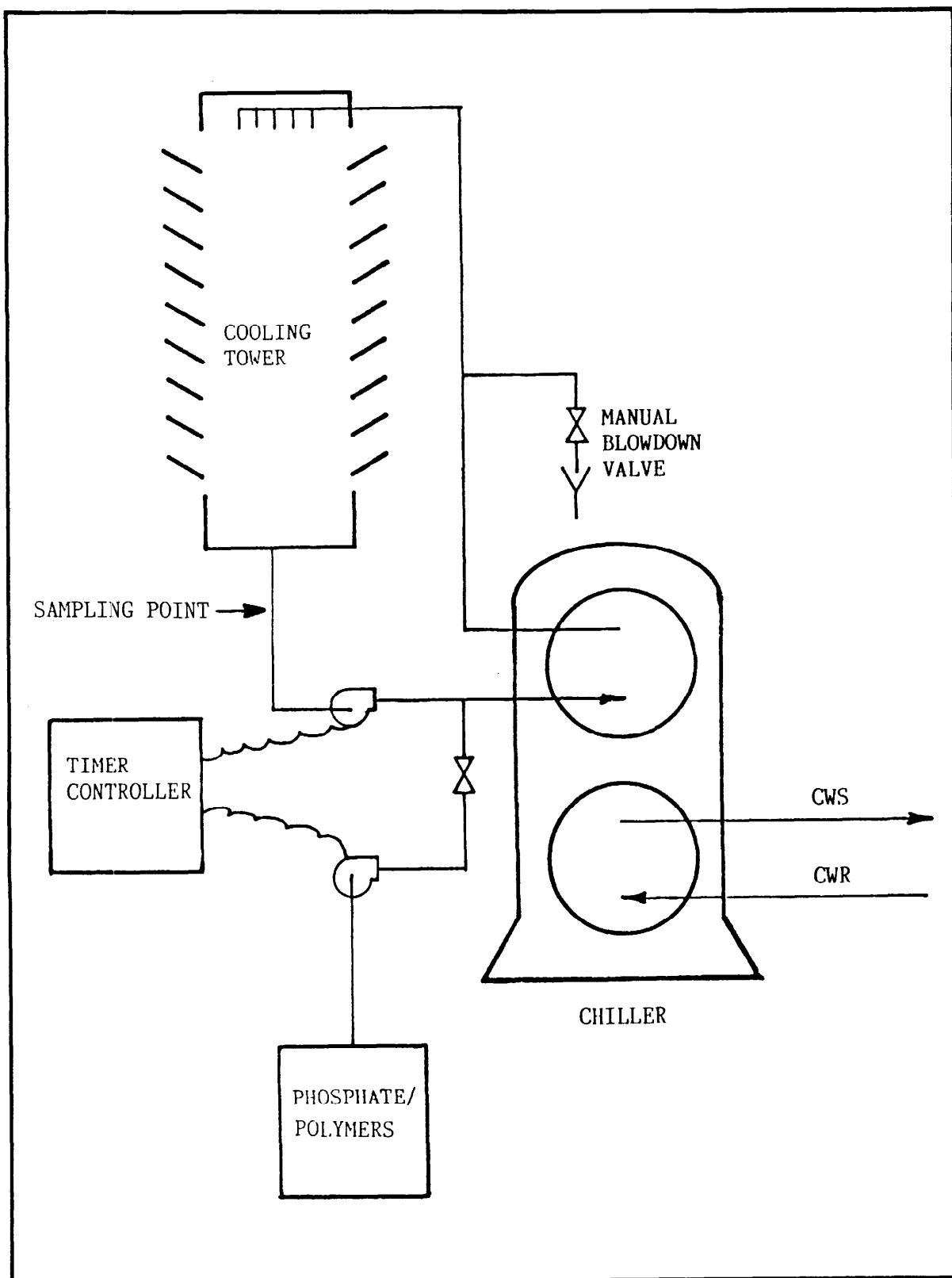
FIGURE C-17
Typical water treatment equipment configuration for a cooling tower
with only manual controls.

This section presents the specific procedures for treating the water in an open loop condenser water system. Each Bill of Attendance is presented on a separate page for ease of copying these procedures for the mechanical rooms.

The following stepby-step procedures will be performed once per week after the cooling season begins and cease at its completion for cooling towers idle during the heating season:

Step no.	Description

1   Obtain a sample of the open loop condenser water in the distribution system from any valve on the tower, chiller or distribution system. Insure that the make-up valve is closed before taking the sample and re-opened immediately afterwards. Allow the water to flow until the line is free of sediment and rust.

2   Perform the following tests:

* Phosphate

* pH

* Conductivity

* Biocide

3   Record the results in the water treatment log for the unit. Use a form similar to that provided as page B-4 of this document. If the pH is well outside the limits, the solution is heavily rust colored, or the water has a heavy musty smell, the entire system should be drained, refilled with potable water, and Step 2 repeated.

4   Calculate the necessary amounts of phosphate/polymer mixture and the biocide(s).

5   If a shot feeder is employed for water treatment chemical injection, insure the isolation valves of shot feeder are closed. Open the drain valve and then the top cap. When the shot feeder is half emptied, close the drain valve and add the necessary chemicals. Secure the top cap. Open the isolation valves on the shot feeder and close the by-pass valve. Wait at least five minutes while the circulating pump is "ON" before proceeding to the next step.

6   Open the bypass valve for the shot feeder and then close the isolation valves.

7   Record the quantities of chemicals added in the water treatment log. This typically will be confined to the replacement of a given chemical drum with a full container. Include any comments or discrepancies.

8   Remove all empty chemical storage drums from the mechanical room.

GLOSSARY

NOTE: Certain license is taken with strict semantic interpretation of the following terms, to present definitions related specifically to water treatment technology.

Absorption, Absorbent -- To take up in the fashion of a sponge, into the physical structure of a solid without a chemical reaction.

Acid -- A solution that has a pH less than 7.

Acid Attack -- Corrosion caused by an acid.

Activated Charcoal -- Charcoal that has been processed to increase its surface area; used as a filter medium.

Adsorption, Adsorbent -- The physical adhesion of a thin layer of molecules or colloids to surfaces of solids without a chemical reaction.

Alkalinity -- Presence of acid neutralizing minerals in water. Alkalinity ceases to exist at a pH near 4.4 units. (See M Alkalinity)

Alloy -- A substance composed of two or more metals combined by heating.

Amines -- Compounds derived from ammonia (NH_3) by replacement of one, two or three of the hydrogen atoms with one to three alkyl groups. Commonly used for protection of condensate systems.

Anion -- A negatively charged ion.

Anion Exchange -- Exchange of anions in a resin bed.

Anion Interchange -- Displacement of one negatively charged particle by another on an anion exchange material.

Anion Resin Beads -- Resin beads in an ion exchanger that attract certain anions.

Anode -- The electrode of an electrolytic cell at which oxidation is the principal reaction. In engineering terms, the negative terminal of a cell.

Anthracite Coal -- Hard coal that can be used as a filter medium.

Approach Temperature -- In a cooling tower, the difference between the temperature of the cooled water in the sump of the tower and the wet bulb temperature.

Backwash -- That part of the operating cycle of an ion exchange or filtration process where a reverse upward flow of water expands the bed, effecting physical changes such as loosening the bed to counteract compacting, stirring up and washing off light, insoluble contaminants to clean the bed, or separating a mixed bed into its components.

Base Exchange -- Property of trading anions by insoluble, naturally or synthetic occurring materials. Developed to a high degree of specificity and efficiency in synthetic resin adsorbents.

Batch Operation -- Use of ion exchange resins to treat a solution in a container to exchange ions. Accomplished by agitation of the solution and subsequent decanting of treated liquid. Any process operation that is not continuous.

Bed -- Ion exchange resin contained in a column.

Bed Depth -- Height of the resinous material in the column after the exchanger has been conditioned for effective operation.

Bed Expansion -- Effect produced during backwashing: resin particles become separated and rise in the column. Expansion of the bed due to the increase in space between resin particles may be controlled by regulating backwash flow.

Bicarbonate -- Compounds which on dissolving produce HCO_3^{-1} ion, e.g. $NaHCO_3$, $Ca(HCO_3)_2$.

Bicarbonate Alkalinity -- Presence in a solution of bicarbonate. When these salts react with water the solution becomes alkaline.

Biochemical Oxygen Demand (BOD) -- Quantity of oxygen required for biological oxidation of organic substances under test conditions.

Biodegradable -- A quality leading to chemical degradation of a substance to a benign form when exposed to the environment.

Biological Deposits -- Deposits composed of either microscopic organisms, such as slimes, or macroscopic organisms, such as barnacles. Slimes are usually gelatinous or filamentous.

Blowdown (Bleed) -- Removal of a portion of water contained in a boiler drum, cooling tower basin, etc., to control concentration of impurities. (See Cycles of Concentration.) Used for scale control; continuous blowdown is the better method.

Boiler Water -- A term construed to mean a representative sample of circulating boiler water, after generated steam has been separated, and before incoming feedwater or added chemicals are mixed with it.

Boiling Out -- Treatment of the waterside of boilers and piping systems with hot, strong chemicals to remove oil, grease, temporary coatings, and some flaky surface oxides and mill scale.

Brackish Water -- Water having a dissolved solids content in the range of approximately 5,000 mg/L to 10,000 mg/L.

Breakthrough -- First appearance in a solution flowing from an ion exchange unit of unabsorbed ions similar to those that deplete activity of the resin bed. Breakthrough is an indication that regeneration of the resin is necessary.

Breakpoint Chlorination -- Addition of sufficient chlorine to satisfy chlorine demand and produce free residual chlorine.

Brine -- A salt (usually NaCl) solution of variable strength used in regeneration of Zeolite water softeners.

Calcium Carbonate Equivalent -- Concentration of ions expressed in terms of $CaCO_3$. Because its molecular weight is 100 g/m and equivalent weight is 50 g/m, it provides a convenient unit of exchange for expressing the equivalent weights of all ions in water. (Analogy: All international monetary units expressed in terms of dollar value)

Capacity -- Amount of exchangeable ions that an ion exchange unit will remove from a solution. This quality may be expressed as kilograins per cubic foot, gram-milliequivalents per gram, pound-equivalents per pound, gram-milliequivalents per milliliter, etc., where numerators of the ratios represent weight of ions adsorbed and denominators represent weight or volume of adsorbent.

Carbonaceous Exchangers -- Ion exchange materials prepared by sulfonation of coal, lignite, peat, etc.

Carbonate -- An anion with the formula CO_3^{-2} whose presence affects the alkalinity of a solution.

Carryover -- Process that transports impurities in boiler water into steam areas in water droplets by foaming or entrainment.

Cathode -- The electrode of an electrolytic cell where reduction is the principal reaction. In engineering terms., the positive terminal of a cell.

Cation -- A Positively charged ion.

Cation Resin Beads -- Resin beads in an ion exchanger that attract certain cations.

Caustic -- Solution that contains hydroxyl ions typically from sodium or potassium hydroxide.

Caustic Attack -- Corrosion caused in an alkaline solution enhanced by tensile stresses, metal working operations, or compositional differences in the metal surfaces.

Channeling -- Cleavage and furrowing of a bed caused by faulty operational procedures. The solution being treated, following paths of least resistance, runs through these furrows, and fails to make adequate contact with the bed.

Chelate, Chelant -- Highly soluble molecules, usually organic, that react with metal ions and keep them in solution.

Chemical Oxygen Demand (COD) -- Quantity of oxygen, required under specific conditions for oxidation of waterborne organic and inorganic matter.

Combined Chlorine Residual -- Total amount of free and combined chlorine remaining in water after the chlorine demand has been satisfied.

Chlorine Demand -- Difference between the amount of chlorine applied to a water and the amount of free combined or total available chlorine which remains after a specific contact time.

Clarifier -- Water treatment equipment used to remove suspended matter from raw water.

Clean Steam--Steam meeting NAVSEA requirements.

Closed System -- Water system that is not exposed to atmosphere.

Colloid -- Particles of very fine particle size, usually 10^{-5} to 10^{-7} cm. in diameter too small to settle.

Color Throw -- Discoloration of liquid passing through an ion exchange material; the flushing from resin interstices of traces of colored organic reaction intermediates.

Column Operation -- Upflow or downflow of solution through ion exchange resins.

Combined Residual Chlorine -- Refers to the three different chloramines formed when chlorine reacts with ammonia. (See breakpoint chlorination)

Concentration -- An expression of the quantity of a solute in a solvent, e.g. mg/liter.

Condensate -- The liquid that condenses from cooled steam.

Conductivity -- Measure of electrical conductance expressed as mhos (reciprocal of ohms, the measure of resistivity.)

Corrosion Products -- Compounds formed by chemical or electrochemicalreaction between a material, usually a metal and its environment.

Counter Current Regeneration -- When more efficient chemical utilization is required for regeneration of ion exchange resins service flow is upward through packed resin while chemical injection is downward or countercurrent. This system requires more sophistication than concurrent methods.

Coupons -- Polished metal strips of specified size and weight used to detect the corrosive action of liquid or gas products or to test the efficiency of corrosion-inhibitor additives.

Crosslinkage -- Process which forms a 3-D polymer when intermolecular forces connect adjacent chains. These forces range from hydrocarbon bonds to ionic bonds.

Cycles of Concentration (COC) -- A ratio of the concentration of solids in a boiler or a cooling tower water to the concentration of the same solids in the makeup water. Since chloride ions are highly soluble, the ratio of chloride ion in circulating water relative to that in makeup water is typically used to calculate the COC. Sometimes conductivity of the various solutions can also be employed for this measurement.

Deaeration -- Removal of dissolved air from a liquid (usually water).

Degasification -- Removal of any dissolved gaseous product from a liquid.

Deionization -- Removal of cations and/or anions from water by ion exchange.

Demineralizer -- See Ion Exchanger.

Demineralizing -- See Deionization.

Density -- In demineralization, weight of a given volume of exchange material, backwashed and in place in a column.

Diatomaceous Earth (DE) -- Used as a filter precoat in septum filtration. DE is the remains of trillions of tiny diatom skeletons deposited as silica mineral structures.

Dissolved Solids -- See Total Dissolved Solids.

Dissociation -- See Ionization.

Distribution Ratio -- A measure of the ability of certain amines to enter the condensate (water phase) is indicated by this vapor-t&quid ratio. The concentration of the amine in both phases is compared (e.g. morpholine 0.4 to 1.0 and cyclohexylamine 4.0 to 1).

Downflow -- Conventional direction of solutions processed in ion exchange column operation.

Efficiency -- Effectiveness of the operational performance of an ion exchanger. Efficiency in the adsorption of ions is expressed as the quantity of regenerant required to remove a specified unit weight of adsorbed material, e.g., pounds of acid per kilograin of salt removed.

Effluent -- The emergent solution that exits any process.

Electrodialysis -- Semipermeable membranes having anion and cation exchange properties, under the influence of electrical current, remove salts from water. Used when TDS is 500 to 5000 ppm as pre-treat for deionizers or non-critical water.

Electrolyte -- A chemical compound that dissociates or ionizes in water to produce a solution that will conduct an electric current,

Elution -- The process of extracting one solid from another.

Equivalent Per Million (epm) -- A unit chemical equivalent weight of solute per million unit weights of solution. Concentration in equivalents per million is calculated by dividing concentration in parts per million by the chemical weight of the substance or ion.

Exchange Velocity -- The rate one ion is displaced from an exchanger in favor of another.

Exhaustion -- State when a resin is no longer capable of useful ion exchange; the depletion of an available supply of ions in an exchanger.

Filter -- Device that traps solids but allows a fluid to pass through.

Filter Medium -- The part of a filter that traps solids.

Fines -- Extremely small particles of ion exchange materials.

Flashing -- Rapid evaporation of water when a sudden decrease of pressure on the water reduces the pressure to less than that of the vapor phase.

Flow Rate -- Volume of solution passing through a specified quantity of resin within a specified time. Usually expressed in terms of gallons per minute per cubic foot of resin, as milliliters per minute per milliliter of resin, or as gallons per square foot of resin per minute.

Foaming -- Evolution of froth due to agitation and increased surface tension of boiler water when dissolved solids concentrations are high.

Fouling (Biological) -- Clogging of a heat exchange surface by sand, silt, clay, corrosion products and microbial activity. Deposits of airborne or waterborne particles on a heat exchange surface. Also refers to organic materials plugging ion exchange resins and RO membranes.

Free Available Chlorine Residual -- Residual chlorine existing in water as the sum of hypochlorite ions, and hypochlorous acid.

Freeboard -- Space provided above a resin bed in an ion exchange column to allow for expansion during backwashing without loss of resin to drain.

Free Mineral Acidity (FMA) -- The quantitative capacity of aqueous media to react with hydrogen ions to pH 4.3. At this point, alkaline conditions begin.

Fresh Water -- Water having less than approximately 1,000 mg/L dissolved solids. Usual sodium concentration is 10-100 mg/L (20-200 mg/L as $CaCO_3$).

Gelular Resins -- Standard ion exchange resins having no discrete pores (See macro reticular.)

Grains Per Gallon -- Historical method of expressing water hardness. Because of conversion uses, one grain per gallon equals 17.1 mg/L.

Greensands -- Naturally occurring materials, primarily composed of complex silicates that possess ion exchange properties.

Hardness -- A characteristic of water representing the concentration of calcium and magnesium ions along with other bivalent metal ions in solution. (Expressed typically as $CaCO_3$ in mg/L.)

Head Loss -- Reduction in liquid pressure associated with passage of a solution through a bed of exchange material; a measure of resistance of a resin bed to the flow of liquid passing through it, usually due to fouling.

Hydraulic Classification -- Rearrangement of resin particles during backwash in an ion exchange unit. As backwash water flows up through a resin bed, particles are placed in a mobile condition causing larger particles to settle and smaller particles to rise to the top. Filtered particulates and resin fines are removed at this time, while the beads are regraded or classified.

Hydrogen Cycle -- Term denoting operation of a cation resin that is regenerated with dilute acid.

Hydroxyl -- or Hydroxide ion - along with carbonate and bicarbonate ion it contributes to the alkalinity of a solution. It does not become measurable until the pH >9.6.

Influent -- Solution that enters any process.

Inhibitor -- Any compound that inhibits chemical activity (scale or corrosion) by filming or chemical modification.

Ion -- A positively or negatively charged atom or molecule in solution.

Ion Exchange -- A process interchanging undesirable ions within an absorbent for desireable ions of similar electrical charge.

Ion Exchanger -- A solid material that transfers unwanted ions from raw water to its surface while giving back into the solution a desirable ion species in exchange.

Ionization -- Dissociation of molecules into charged particles or ions.

Leakage -- The phenomenon that occurs when some influent ions are not adsorbed or exchanged and appear in the effluent of an ion exchanger. Usually indicates that the exchanger is near exhaustion.

Lime Softening -- Addition of lime to water to remove hardness and alkalinity by forming insoluble precipitates that are removed by sedimentation and filtration

Localized Attack -- Form of corrosion that only specific areas on a metal surface are affected.

"M" Alkalinity -- Methyl orange alkalinity. In water chemistry testing, the end point at which the indicator methyl orange changes color corresponds to a pH of approximately 4.3 units.

Macroreticular -- A term used to describe ion exchange resins that have discrete pores that give them high resistance to organic fouling and are used ahead of standard gelular resins as protection from organic materials in water.

Magnetite -- Generally a self-limiting type of corrosion product of iron that occurs under low oxygen conditions; the oxide layer that is formed prevents further corrosion.

Makeup -- Water in a cooling tower or boiler used to replenish the system after blowdown, leakage, or other losses.

Mixed Bed Ion Exchanger -- Anion and cation resin beads mixed together in an ion exchanger.

Monomer -- Basic units or simple molecules that combine to form polymers.

Negative Charge -- The fundamental negative charge within an atom, is the electron. An excess of one or more electrons causes the atom to have negative charge. (See anion)

Noble Gas -- Inert gases of the helium family that do not react with other elements under ordinary conditions.

Noble Metals -- Metals such as gold, silver and platinum that are difficult to oxidize and thus resist corrosion under normal conditions.

Once-Through System -- Cooling water used once, then discharged as waste. Condenser circulating water system where water is drawn from a source, used in the system, and returned to the source.

Open System -- Water system that is exposed to atmosphere.

Organic -- Compounds of carbon in combination with other elements.

Osmosis -- A natural process where water passes through a semi-permeable membrane from a solution of lesser concentration to a solution of higher concentration. (See Reverse Osmosis) Flow continues until osmotic pressure is at equilibrium with opposing forces.

Oxidation -- The loss of electrons from an element of that element in a compound. These electrons are gained by another element in the system that is said to he reduced.

"P" Alkalinity -- Phenolphthalein alkalinity. The endpoint corresponding to a pH of 8.3 where phenolphthalein changes color (violet to colorless). It is accepted to represent all of the hydroxide present plus one half of the bicarbonate.

Part Per Billion (ppb) -- Measure of proportion by weight, equivalent to a unit weight of solute per billion unit weights of solution.

Part Per Million (ppm) -- Measure of proportion by weight, equivalent to a unit weight of solute per million unit weights of solution.

> NOTE: One part per million is generally considered equivalent to 1 milligram per liter, but this is not precise. One part per million is equivalent to 1 milligram of solute per kilogram of solution.

Particulate Matter -- Small particles of solid matter (usually with a surface charge) found entrained in gases or suspended in liquid solution.

pH -- A measure of the H^+ concentration of a solution on a scale from 0 (most acidic) to 14 (most alkaline), where a pH of 7 is neutral.

pOH -- An expression of the OH concentration of a solution; the negative logarithm of the hydroxyl ion concentration.

Pitting -- A highly corrosive localized attack that causes pits to form in metal. Usually promoted by stagnant or low velocity conditions and the presence of ions such as chlorides.

Polar Molecule -- A permanent dipole where there is an unequal distribution of charge.

Positive Charge -- Electrical potential acquired by an atom that has lost one or more electrons; a characteristic of a cation.

Precipitate -- Solid material that forms an aqueous solution due to exceeding the permitted solubility of the substance in solution. Such changes in solubility occur from chemical reactions or decrease in the water volume.

Precoat Filter -- A precoat medium, such as diatomaceous earth, is applied as a slurry to a porous septum to produce a filtering surface. Process is usually used to remove very small concentrations of suspended solids.

Priming -- Applied to boilers when water in the boiler drum becomes unstable and extreme level changes occur in different parts of the drum.

Purity -- Meaure of the condition of water with respect to dissolved solids and gases.

Quality -- Applied to steam to denote the amount of liquid carried over with the steam into the system. Quality of 100 percent equals zero carryover.

Raw Water -- Untreated water.

Recirculating System -- A system that continuously recirculates water.

Regenerant -- Solution used to restore activity in an ion exchanger. Acids are employed to restore a cation exchanger to its hydrogen form; brine solutions may be used to convert the cation exchanger to the sodium form. An anion exchanger may be rejuvenated by treatment with an alkaline solution.

Regeneration -- Restoration of exchange capacity in a ion exchanger by replacing ions adsorbed from treated solution by ions that were adsorbed on the resin.

Resin Bead -- A small insoluble porous (usually synthetic) bead that contains electrically charged sites where ions are exchanged; beads may be anion or cation exchangers.

Resistivity -- A measure of resistance offered by a liquid to the flow of electrical current. Pure water has a very large resistivity. Resistivity is the inverse of conductivity.

Reverse Deionization -- The use of an anion exchange unit and a cation exchange unit, in that order, to remove ions from solution.

Reverse Osmosis -- A process that applies an external pressure on a system where osmotic equilibrium exists causing pure water to flow through a semi-permeable membrane leaving the impurities behind.

Rinse -- Operation following regeneration; a flushing out of excess regenerant solution.

Ryznar Stability Index -- An indicator for predicting scaling tendencies of water by quantitatively indicating the amount of $CaCO_3$ that would be formed by water at any temperature up to 200%

Salt -- Class of compounds formed when metal cations combine with non- metal anions, e.g. NaCl, $CuSO_4$.

Salt Splitting -- Conversion of salts to their corresponding acids, and bases; only SC (strong cation) and SB (strong anion) resins can do this, e.g. anion exchanger to base, cation to acids.

Saturated Solution -- A solution that holds the maximum amount of solute.

Scale -- A precipitated deposit of dense adherent material that forms on surfaces in contact with water as a result of physical or chemical change. Growth is slow, crystalline and usually tenacious. (See Sludge).

Sediment -- Solid particles in a liquid system that settle due to gravity.

Settleable Solids -- An impurity that will not dissolve, yet can be readily removed from a solution by a brief period of settling.

Selective Corrosion -- A type of corrosion where a specific metal in an alloy is corroded; other metals are not affected.

Sequester -- To remove from solution by forming stable water soluble complex compounds. (See Chelate).

Sludge -- A form of sediment resulting from soluble salts and suspended solids in feedwater being subjected to evaporation that thus becomes insoluble. They are both discrete and non-uniform. Also in sewage treatment, the organics and microorganisms that breakdown the wastes.

Slug -- A fixed quantity of chemicals supplied to a system without time control.

Sodium Cycle -- Term denoting operation of a cation resin when regenerated with salt.

Solute -- The substance dissolved by a solvent.

Solution -- Homogenous mixture composed of a solute dissolved in a solvent. Solutions can be of several types, although generally considered to be a solid (solute) dissolved in a liquid (solvent). Other examples are alloys and aerosols.

Solvent -- Tile dissolving medium. The dissolved substance is the solute (e.g. salt) in a solvent (water) which together form a solution.

Static System -- Batch use of ion exchange resins, where (since ion exchange is an equilibrium reaction) a definite endpoint is reached involving fixed ratios of ion distribution between the resin and solution.

Sulfonic Acid -- A function HSO^{-3} group on strong cation (SC) resins that remove all raw water cations on the hydrogen cycle.

Suspended Solid -- An impurity that will not dissolve and can only be removed by filtration.

Swelling -- Expansion of an ion exchange bed that occurs when reactive groups on the resin are converted into certain forms.

Throughput Volume -- The sum of the carbonate, bicarbonate and hydroxide ion alkalinity in solution generally determined by the test for "M" Alkalinity.

Total Alkalinity -- The sum of carbonate, bicarbonate and hydroxide ions in solution. Generally determined by the test for "M" alkalinity.

Total Dissolved Solids -- The combination of all solid elements and compounds dissolved in a solvent (usually water).

Turbidity -- Reduction of transparency of water caused by particulate matter.

Upflow -- Operation of an ion exchange unit where solutions are passed in at the bottom and out at the top, during regeneration.

Voids -- Space between the resinous particles in an ion exchange bed.

Volatile Treatment -- Use of vapor phase for coating type of water treatment involving addition of volatile chemicals to water (usually amines to control corrosion).

Water-Formed Deposits -- Any accumulation of insoluble material derived from water or formed by reaction of water on surfaces.

Zeolite -- Synthetic sodium aluminosilicate cation exchange materials (circa 1905). Now refers to any cation exchange process, even though zeolites are rarely used. (See Greensand.)

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